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Oya

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(54) **STEERING ASSIST DEVICE**

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(22) Filed: **Jun. 8, 2016**

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B62D 15/02 (2006.01)
B62D 5/04 (2006.01)
B60R 1/00 (2006.01)

(52) **U.S. Cl.**

CPC ***B62D 15/025*** (2013.01); ***B60R 1/00*** (2013.01); ***B62D 5/0409*** (2013.01); ***B62D 5/0454*** (2013.01); ***B62D 5/0463*** (2013.01)

(58) **Field of Classification Search**

None
See application file for complete search history.

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(57) **ABSTRACT**

In a steering assist device, a correction gain setting unit sets correction gain to one if it determines that that the sign of a lateral deviation change rate is different from that of a second derivative value of a lateral deviation. The correction gain setting unit sets the correction gain to a predetermined value that is larger than one, if it determines that that the sign of the lateral deviation change rate is the same as that of the second derivative value of the lateral deviation. A gain multiplication unit corrects a lane keep assist current value calculated by a lane keep assist current value calculation unit by multiplying the lane keep assist current value by the correction gain set by the correction gain setting unit.

4 Claims, 14 Drawing Sheets

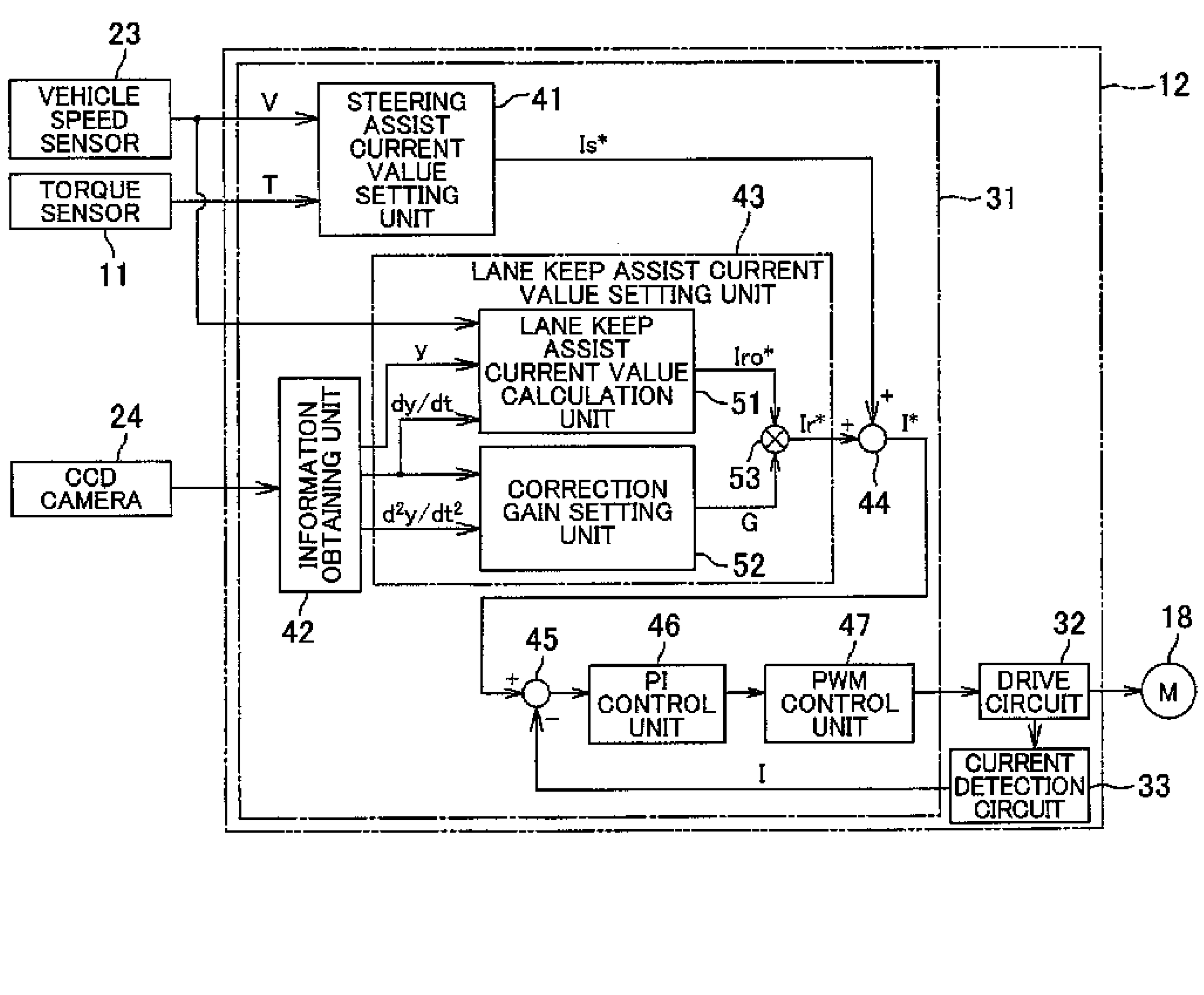


FIG. 1

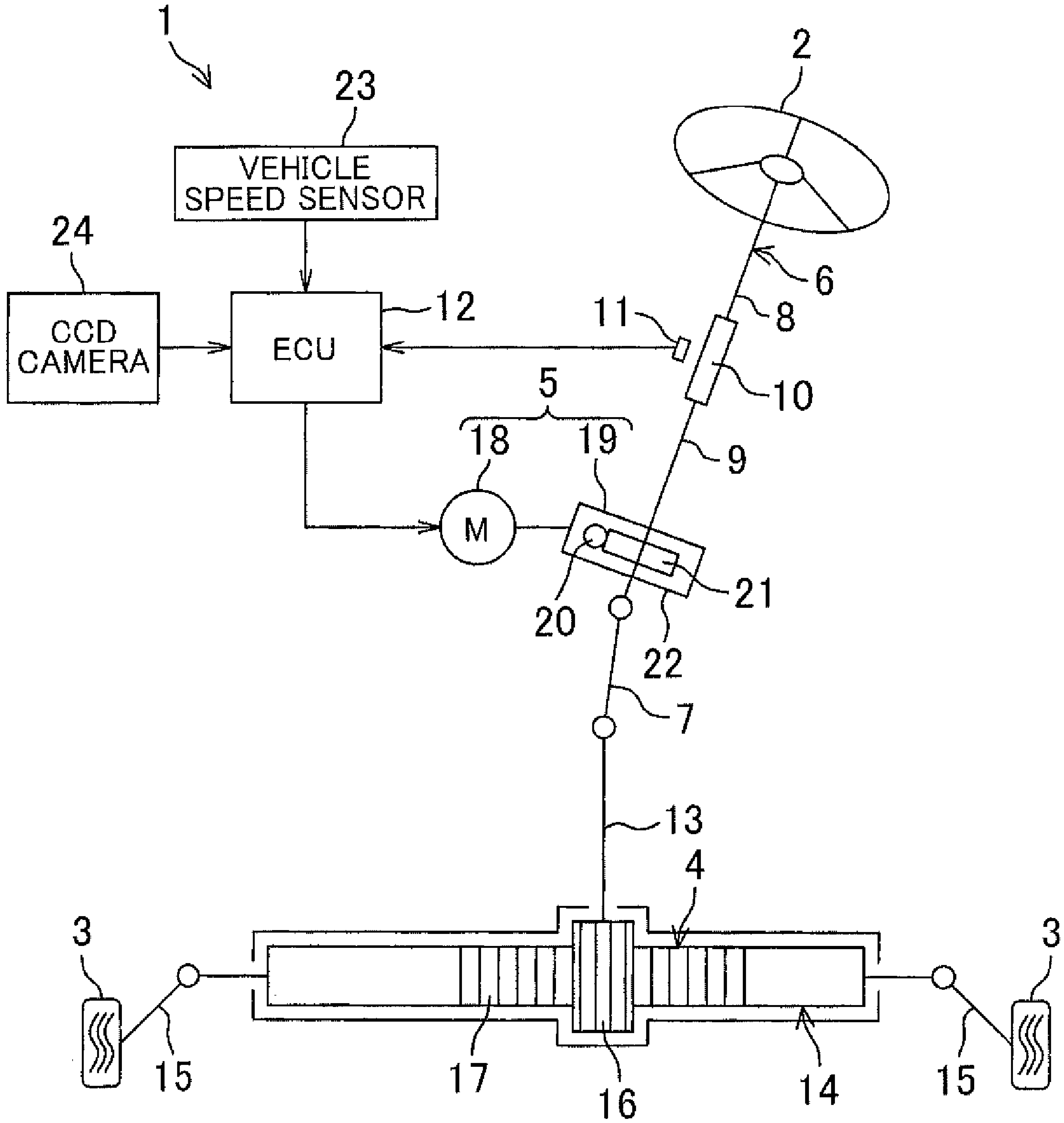

1
23
VEHICLE SPEED SENSOR
24
CCD CAMERA
ECU
12
11
2
6
8
10
5
18
19
9
M
20
21
22
7
13
4
3
15
17
16
14

FIG. 2

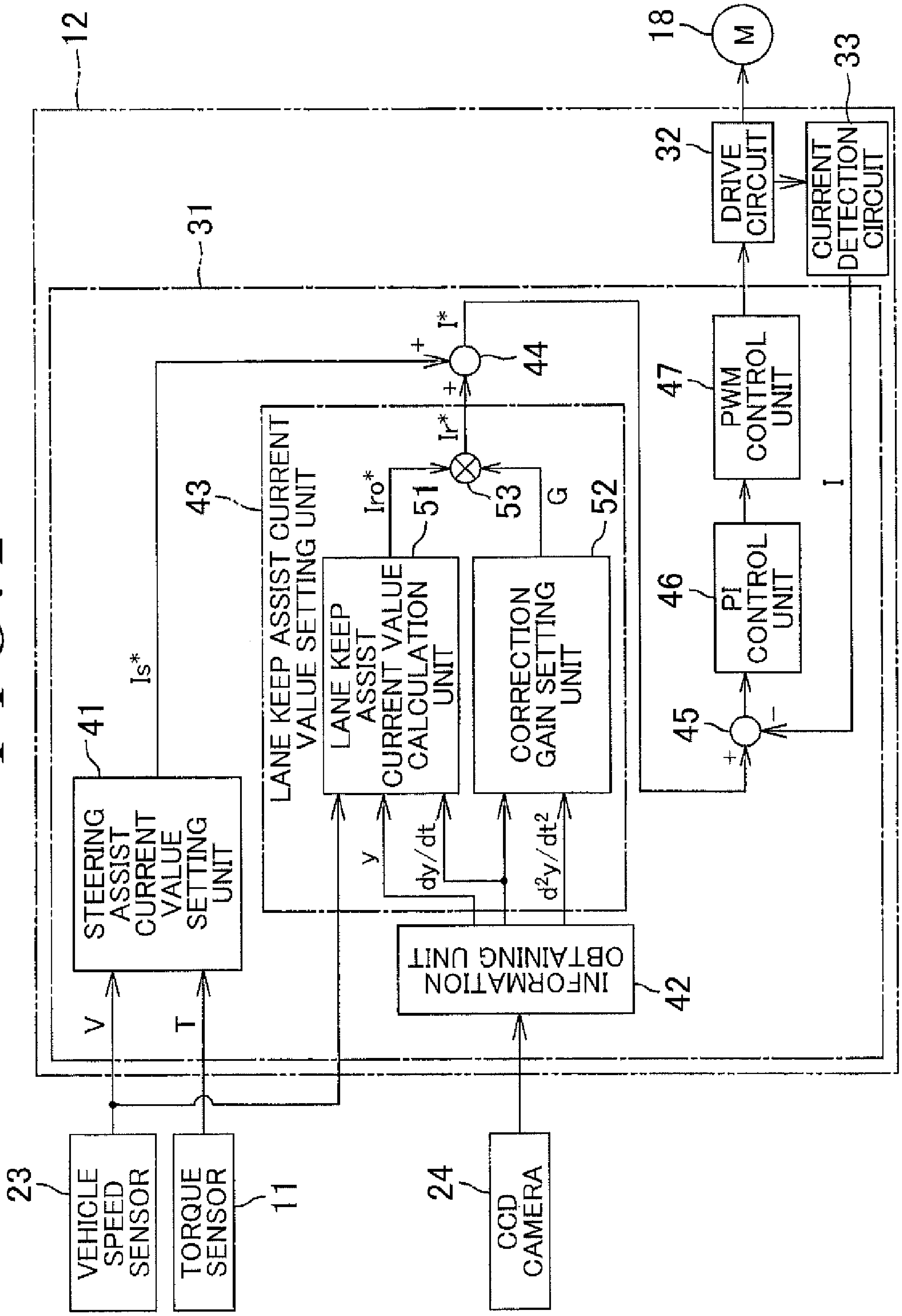

12
31
18
M
32
DRIVE CIRCUIT
33
CURRENT DETECTION CIRCUIT
47
PWM CONTROL UNIT
46
PI CONTROL UNIT
45
44
I*
I
Ir*
53
Iro*
G
51
52
43
LANE KEEP ASSIST CURRENT VALUE SETTING UNIT
LANE KEEP ASSIST CURRENT VALUE CALCULATION UNIT
CORRECTION GAIN SETTING UNIT
41
STEERING ASSIST CURRENT VALUE SETTING UNIT
Is*
y
dy/dt
d2y/dt2
42
INFORMATION OBTAINING UNIT
V
T
23
VEHICLE SPEED SENSOR
TORQUE SENSOR
11
24
CCD CAMERA

FIG. 3

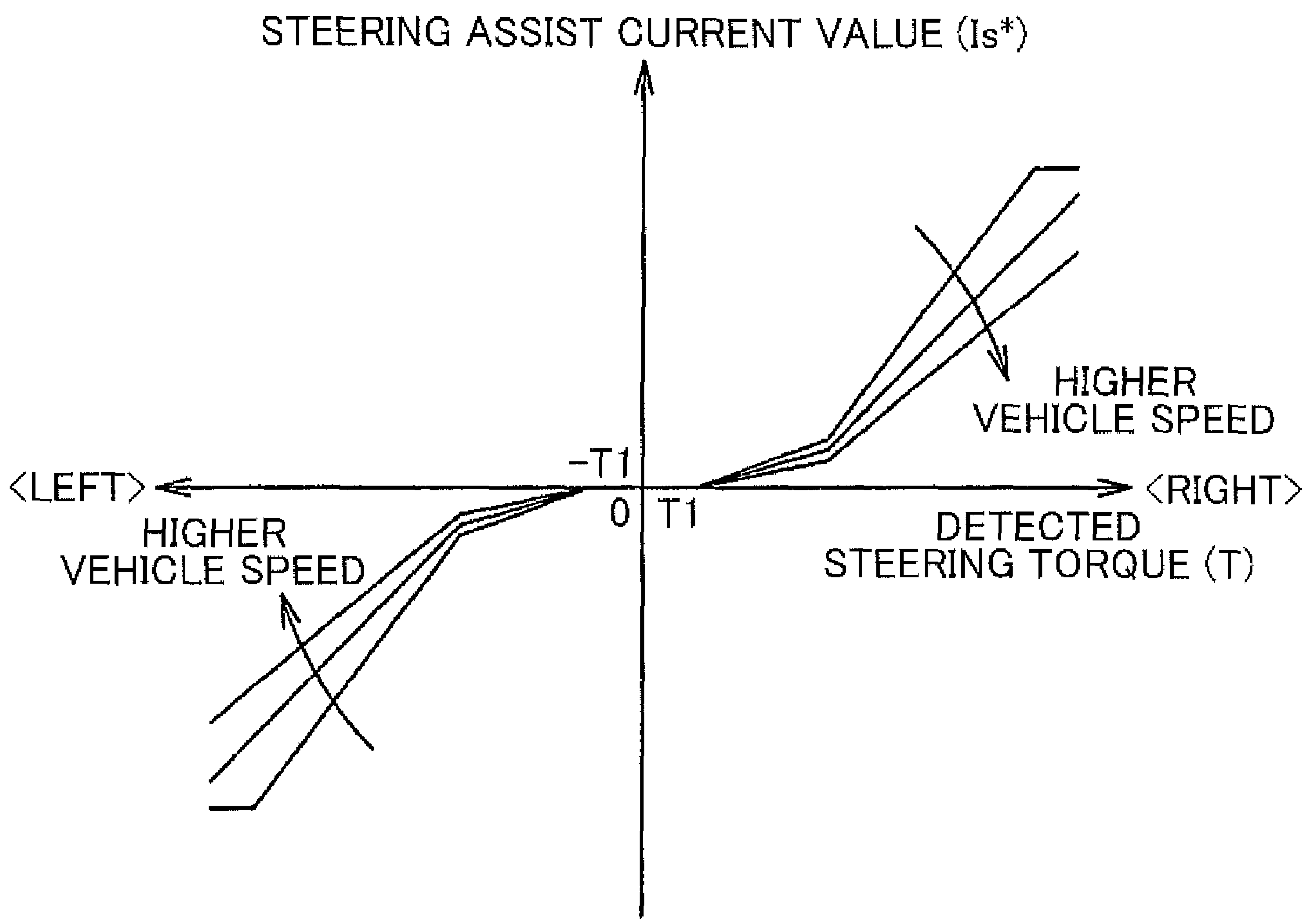

STEERING ASSIST CURRENT VALUE (Is*)
HIGHER VEHICLE SPEED
-T1
<LEFT>
0
T1
<RIGHT>
HIGHER VEHICLE SPEED
DETECTED STEERING TORQUE (T)

FIG. 4

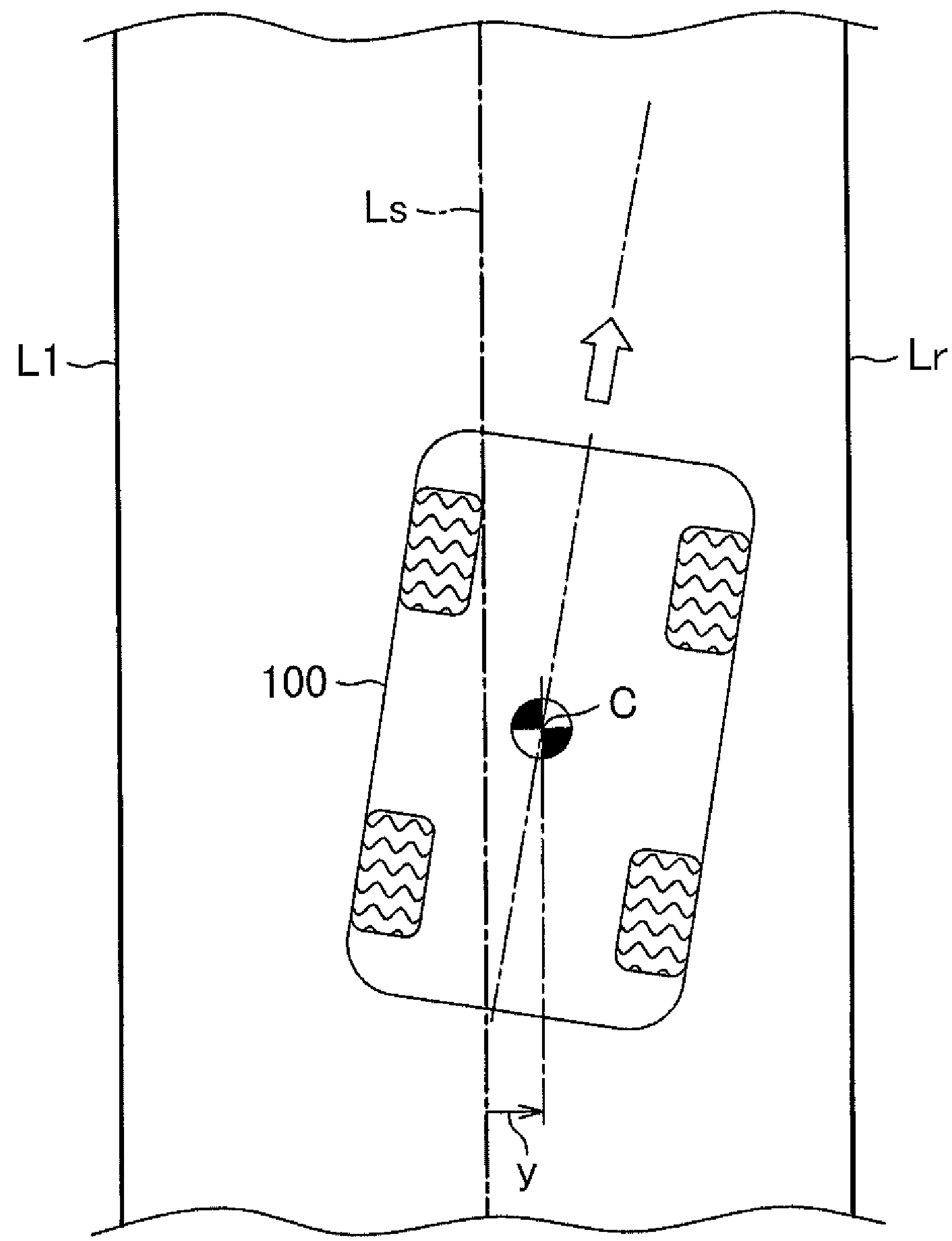


FIG. 5

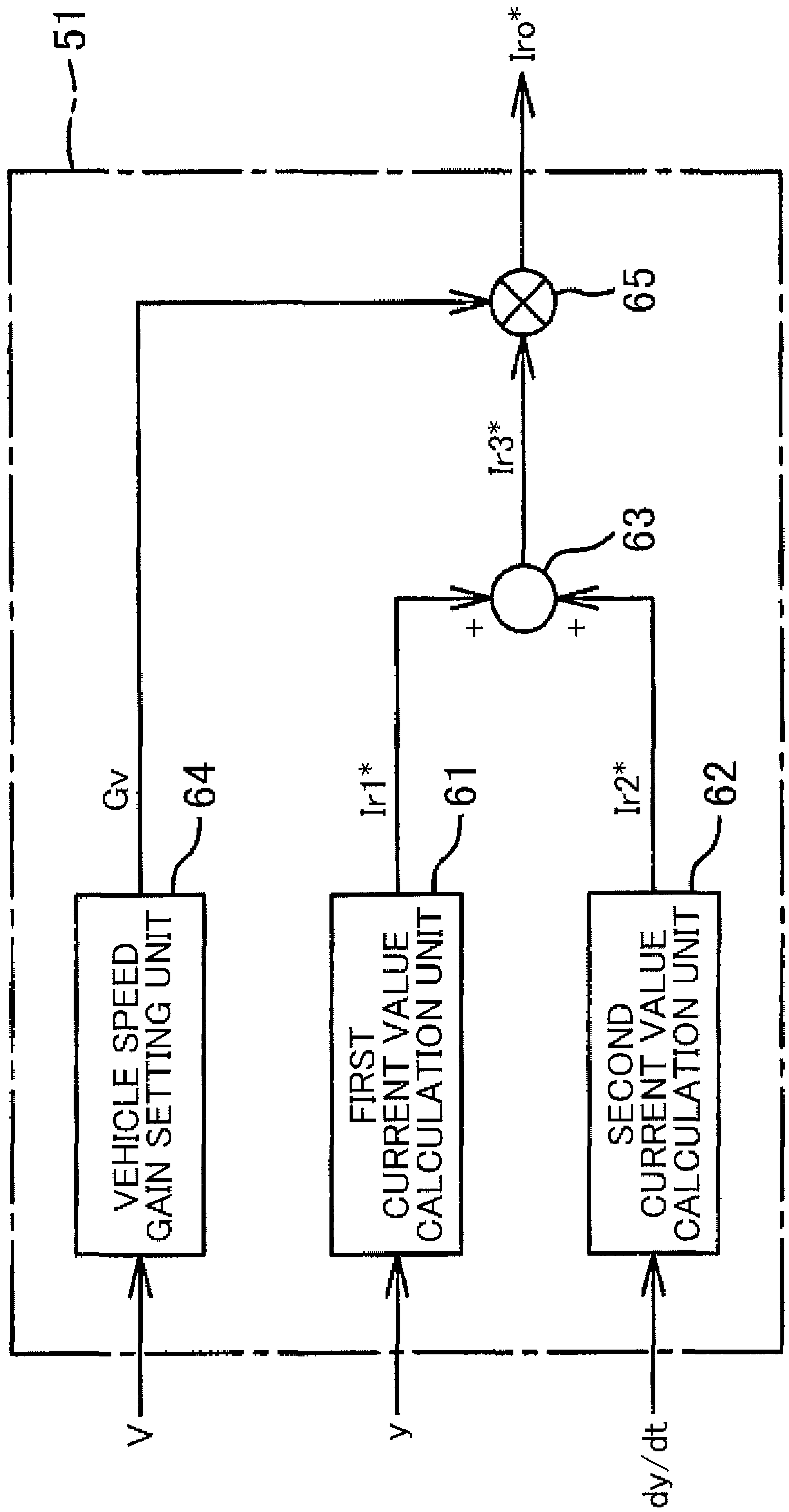

51
Iro*
65
Ir3*
63
+
+
Gv
64
Ir1*
61
Ir2*
62
VEHICLE SPEED GAIN SETTING UNIT
FIRST CURRENT VALUE CALCULATION UNIT
SECOND CURRENT VALUE CALCULATION UNIT
V
y
dy/dt

FIG. 6A

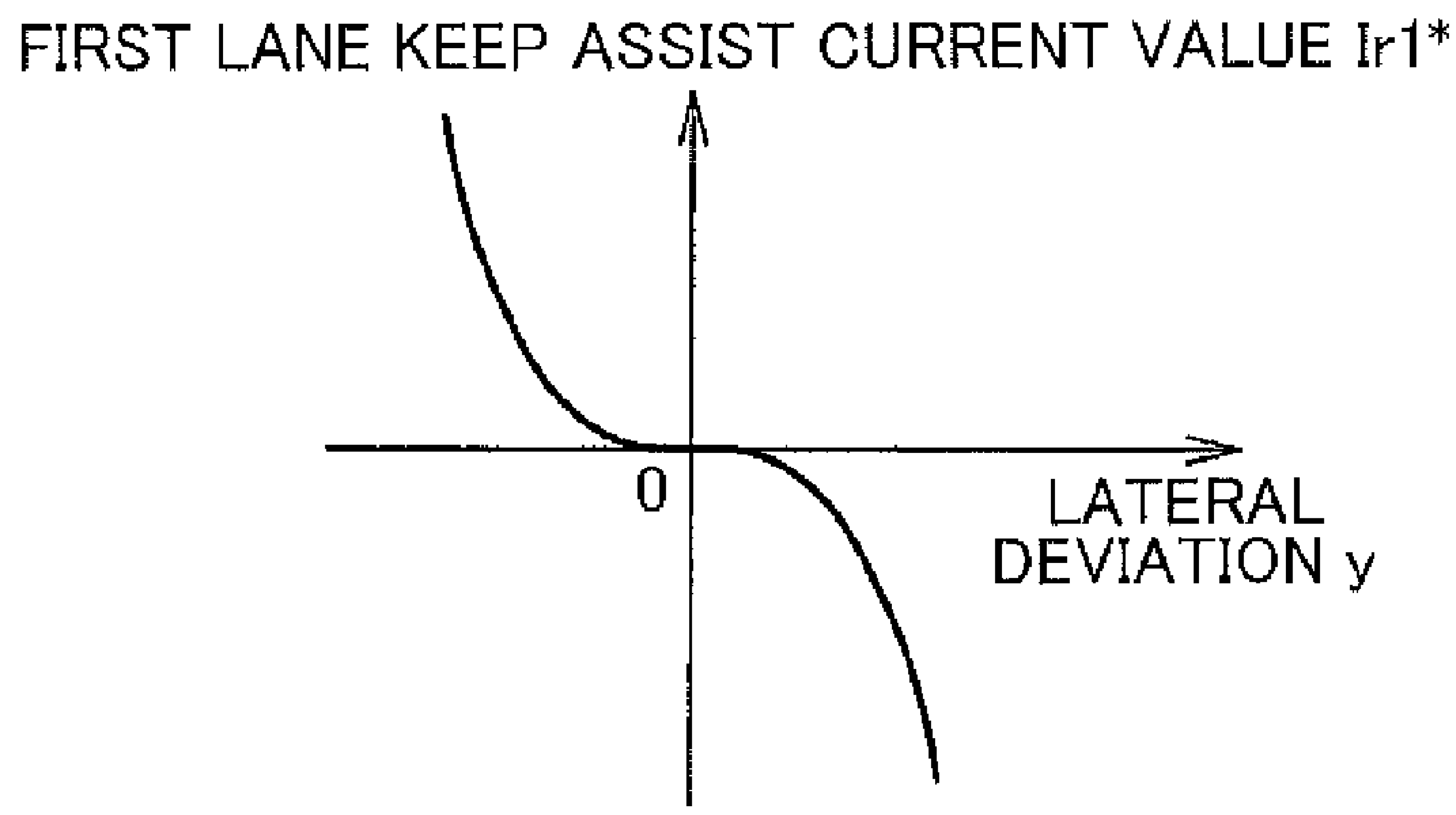


FIG. 6B

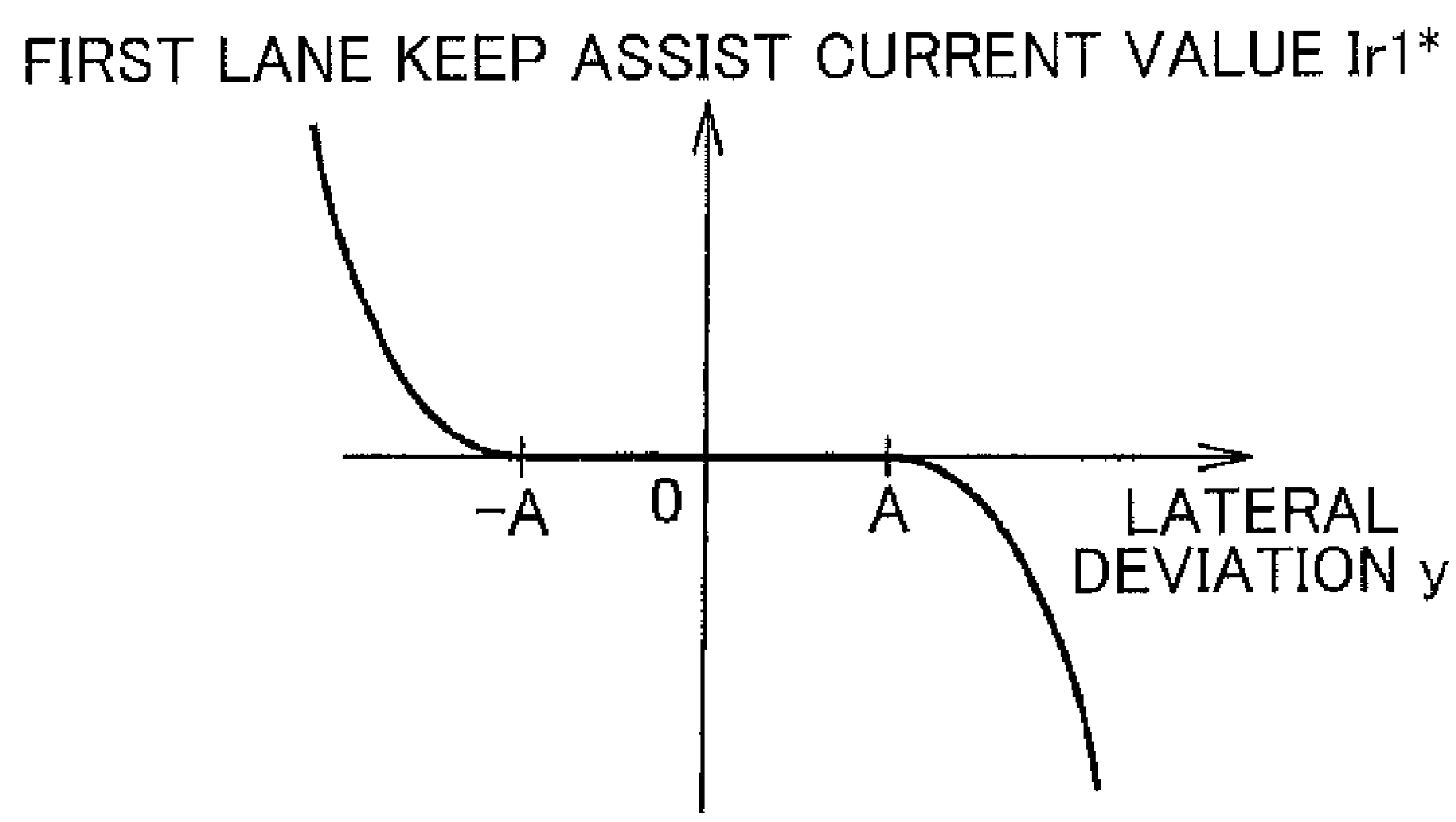


FIG. 6C

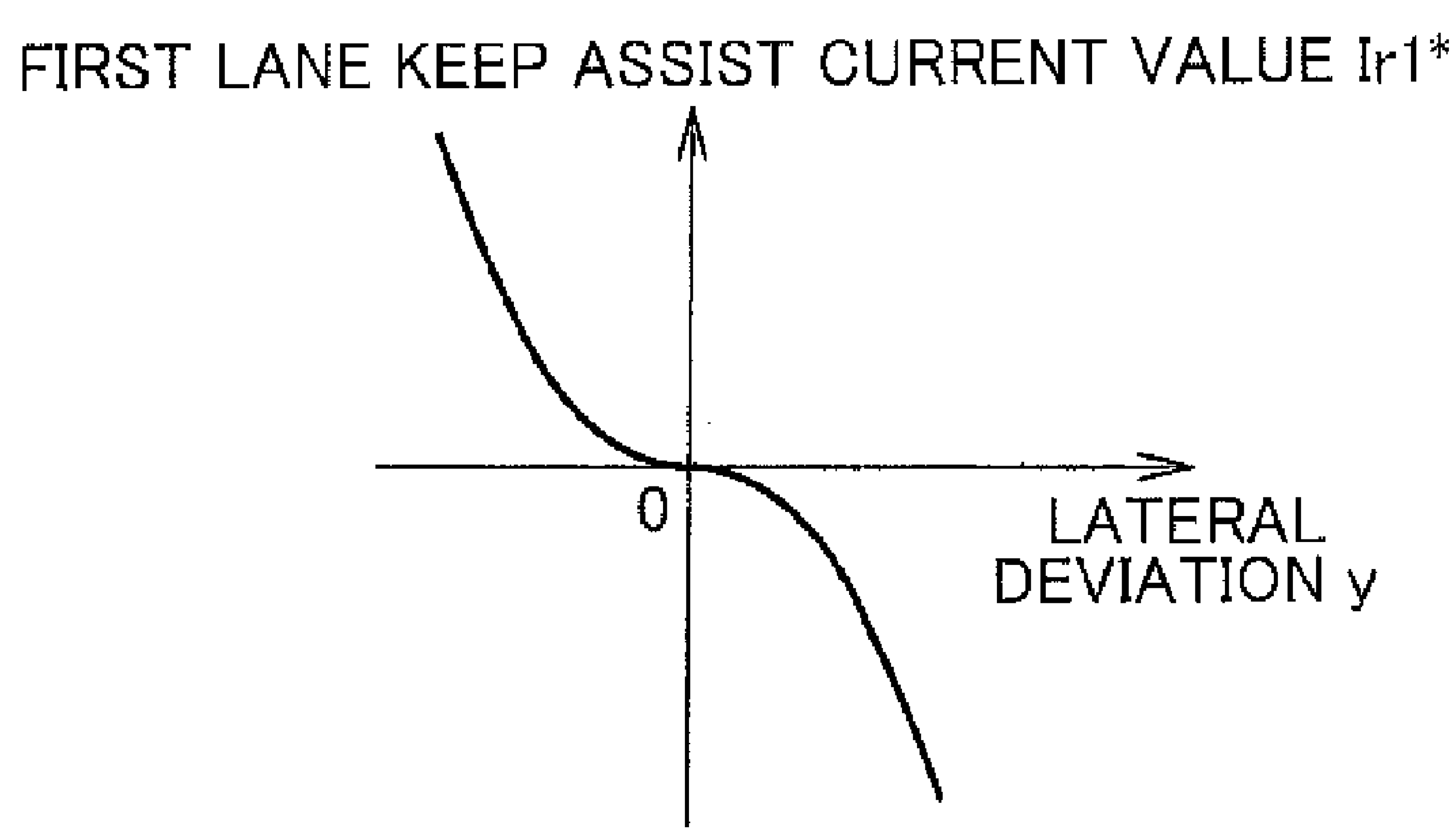


FIG. 7A

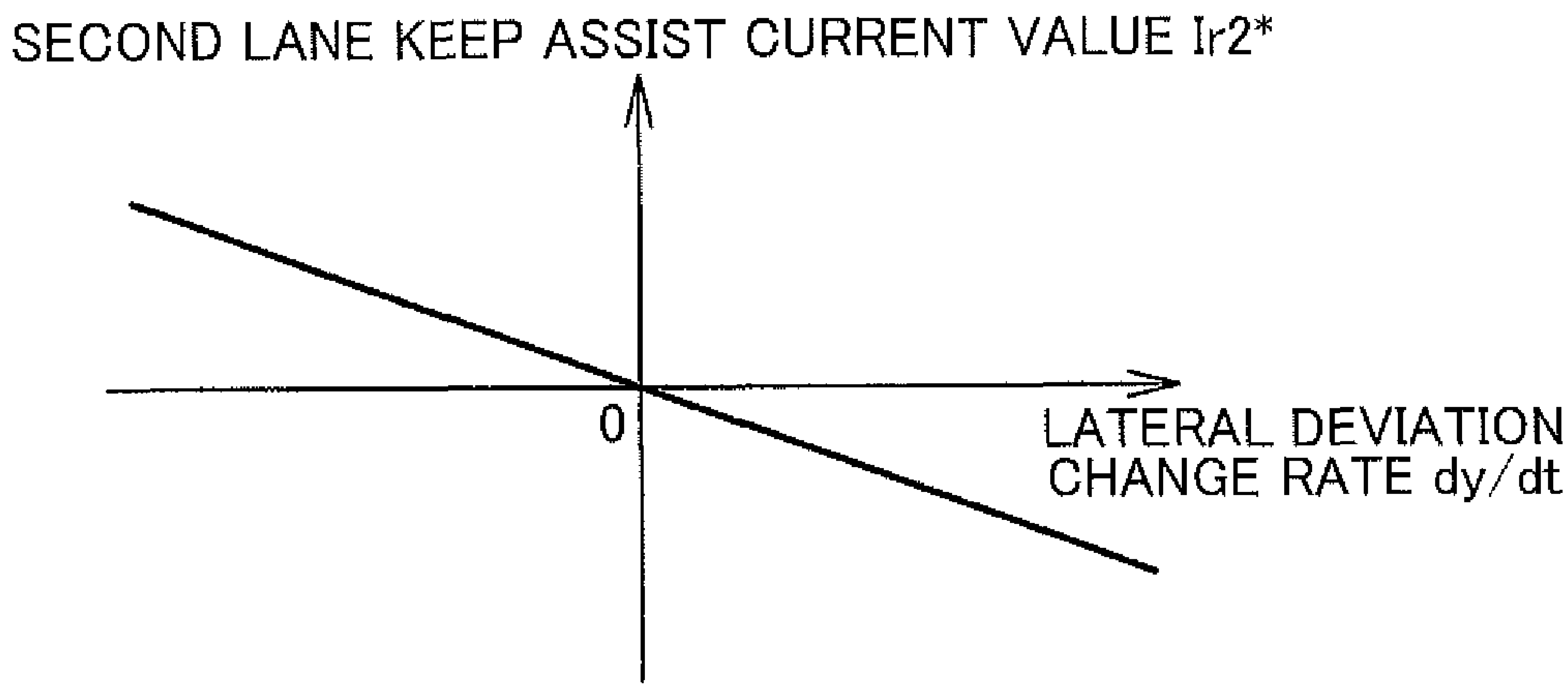

SECOND LANE KEEP ASSIST CURRENT VALUE Ir2*
0
LATERAL DEVIATION CHANGE RATE dy/dt

FIG. 7B

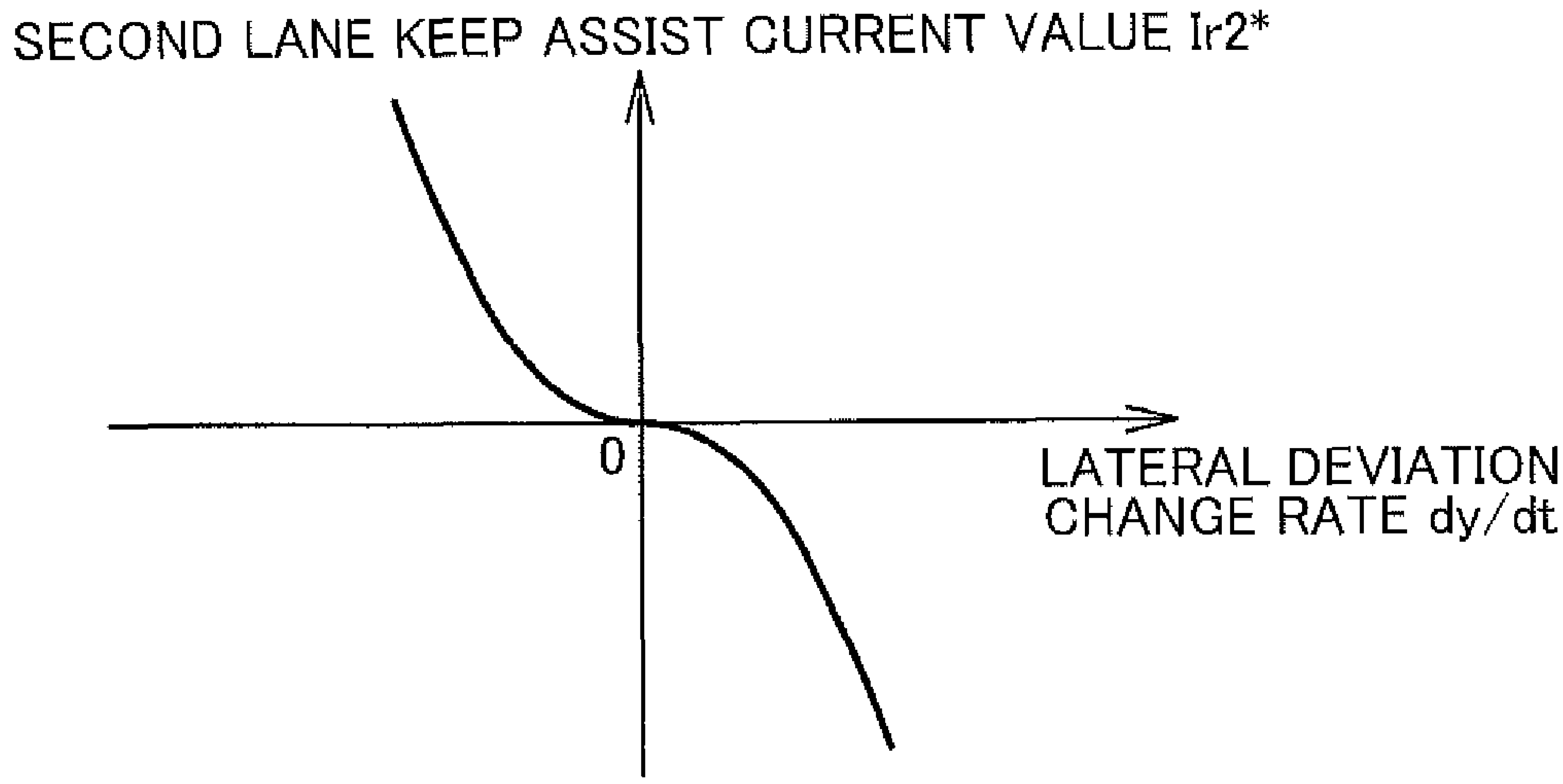

SECOND LANE KEEP ASSIST CURRENT VALUE Ir2*
0
LATERAL DEVIATION CHANGE RATE dy/dt

FIG. 8

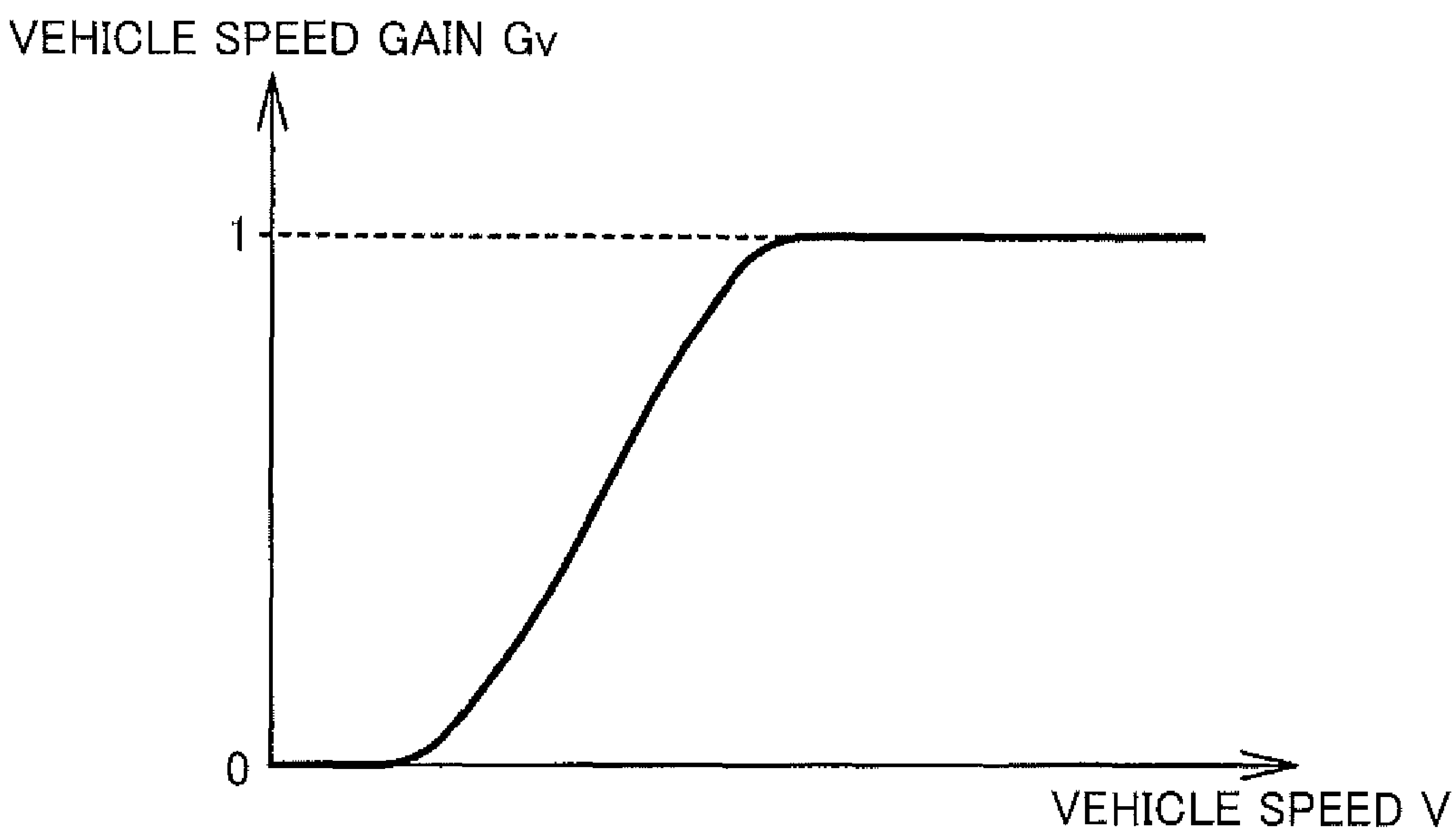


FIG. 9

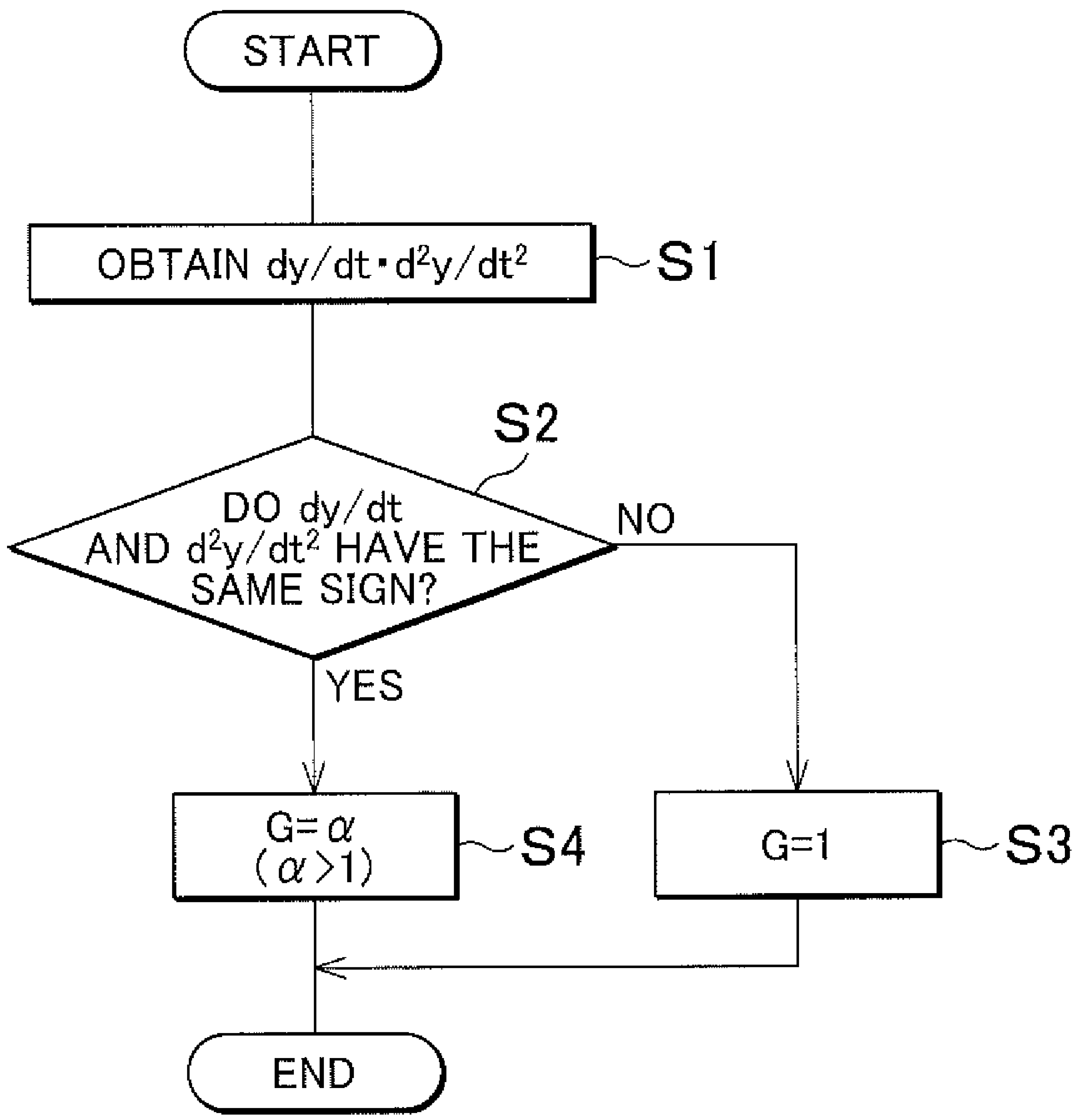

START
OBTAIN dy/dt·d²y/dt²
S1
S2
DO dy/dt AND d²y/dt² HAVE THE SAME SIGN?
NO
YES
G=α (α>1)
S4
G=1
S3
END

FIG. 10

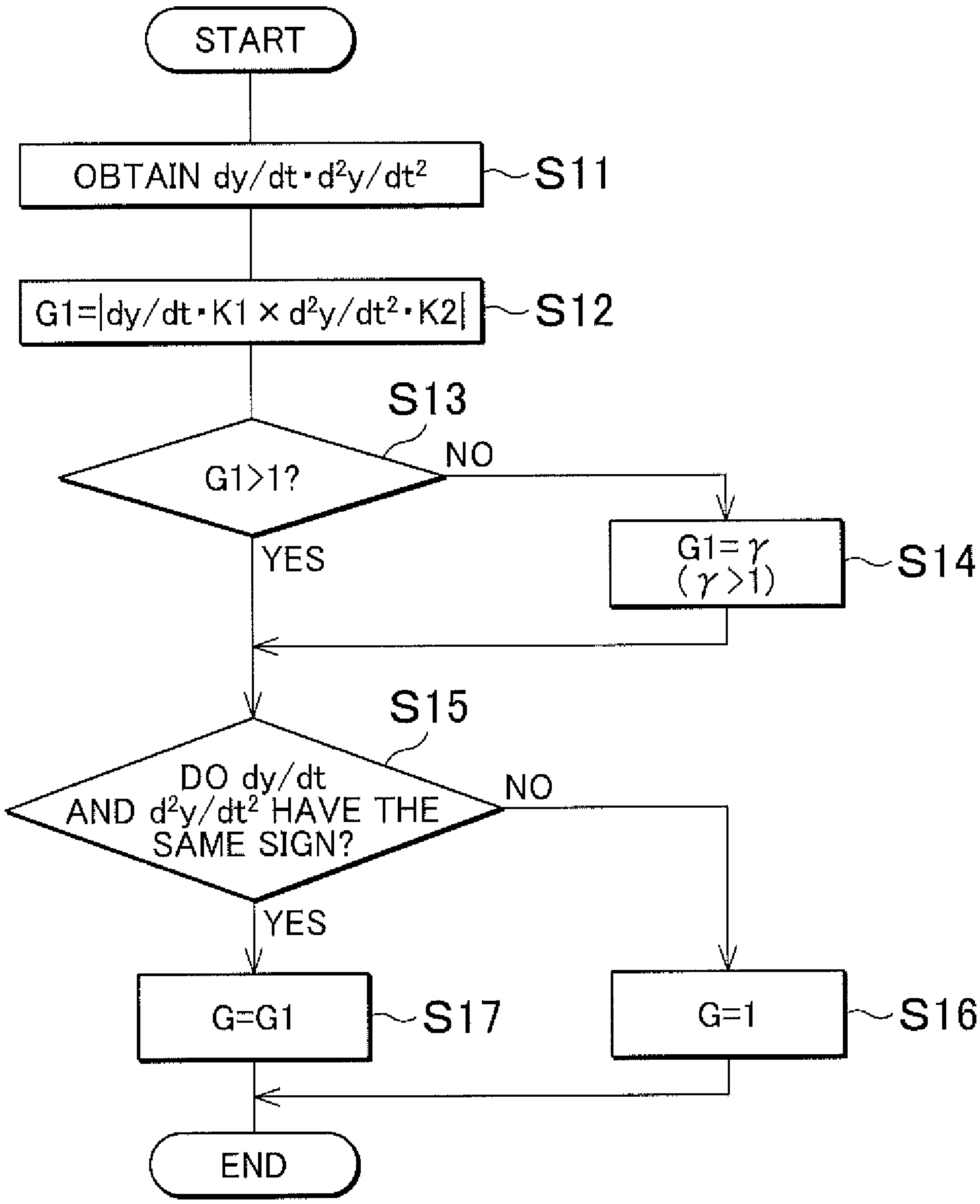

START
OBTAIN dy/dt・d²y/dt²
S11
G1=|dy/dt・K1 × d²y/dt²・K2|
S12
S13
G1>1?
NO
YES
G1=γ
(γ>1)
S14
S15
DO dy/dt
AND d²y/dt² HAVE THE
SAME SIGN?
NO
YES
G=G1
S17
G=1
S16
END

FIG. 11

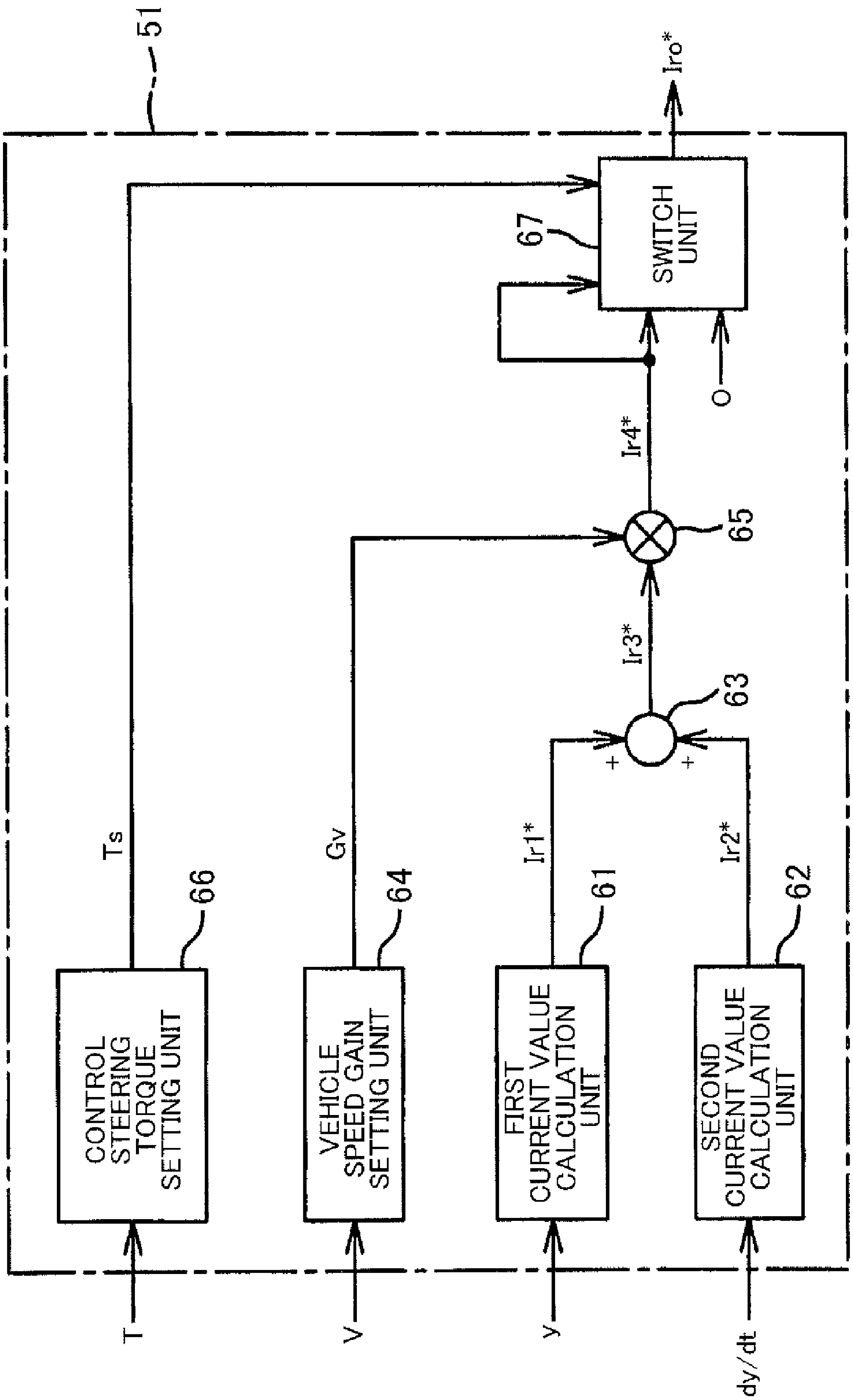

51
CONTROL STEERING TORQUE SETTING UNIT
66
VEHICLE SPEED GAIN SETTING UNIT
64
FIRST CURRENT VALUE CALCULATION UNIT
61
SECOND CURRENT VALUE CALCULATION UNIT
62
SWITCH UNIT
67
63
65
T
V
y
dy/dt
Ts
Gv
Ir1*
Ir2*
Ir3*
Ir4*
Iro*
+
+
0

FIG. 12

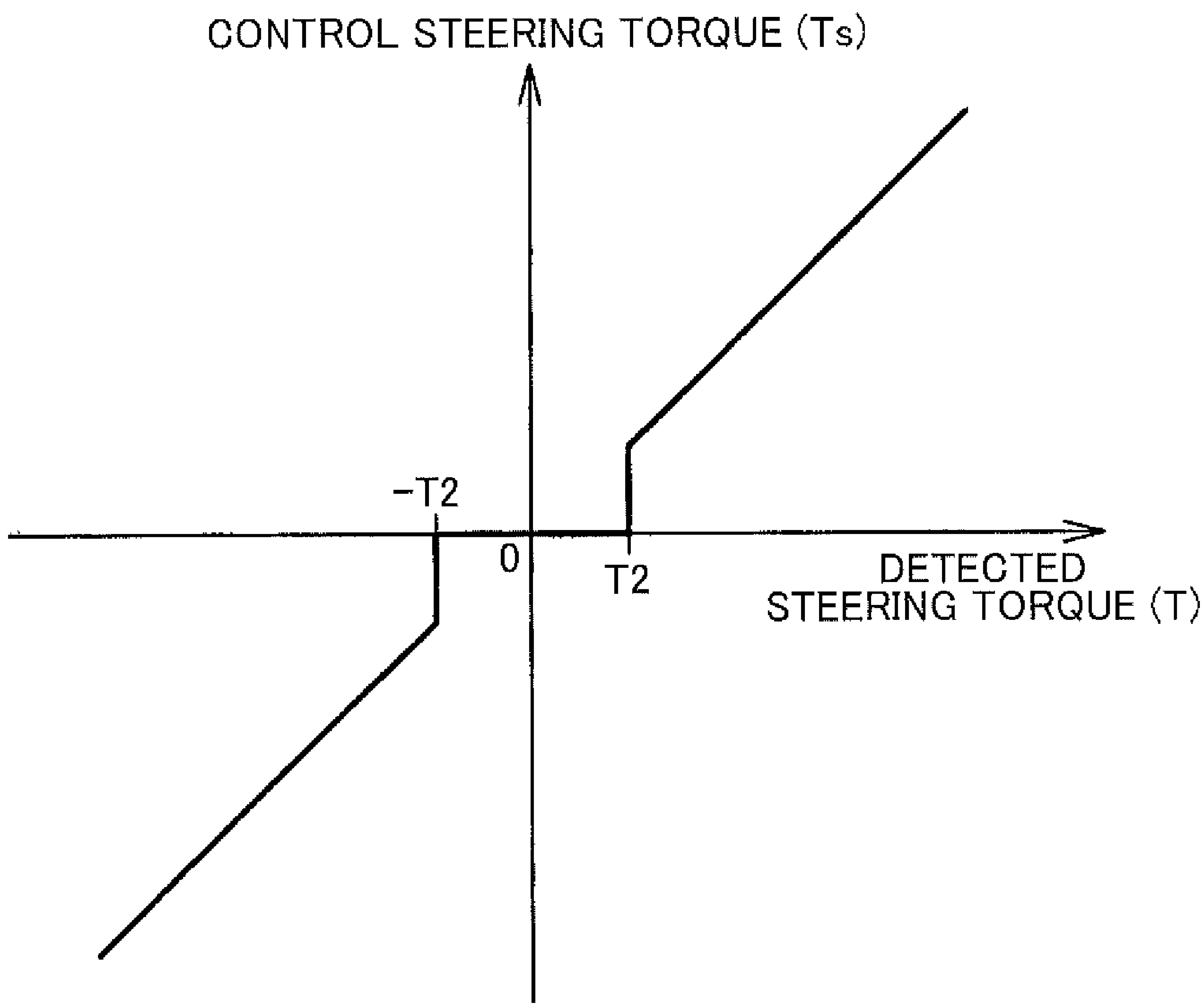

CONTROL STEERING TORQUE (Ts)
−T2
0
T2
DETECTED
STEERING TORQUE (T)

FIG. 13

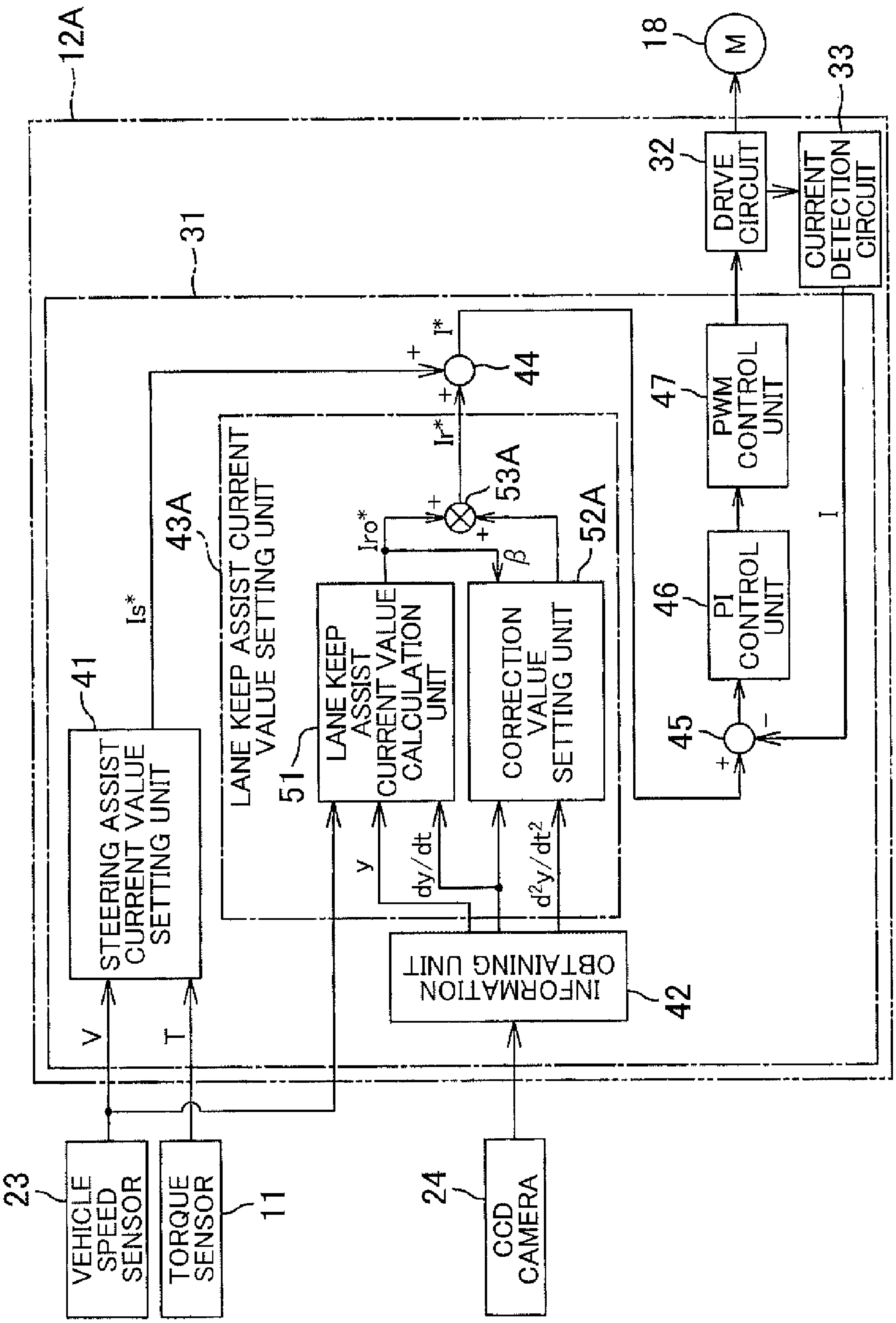
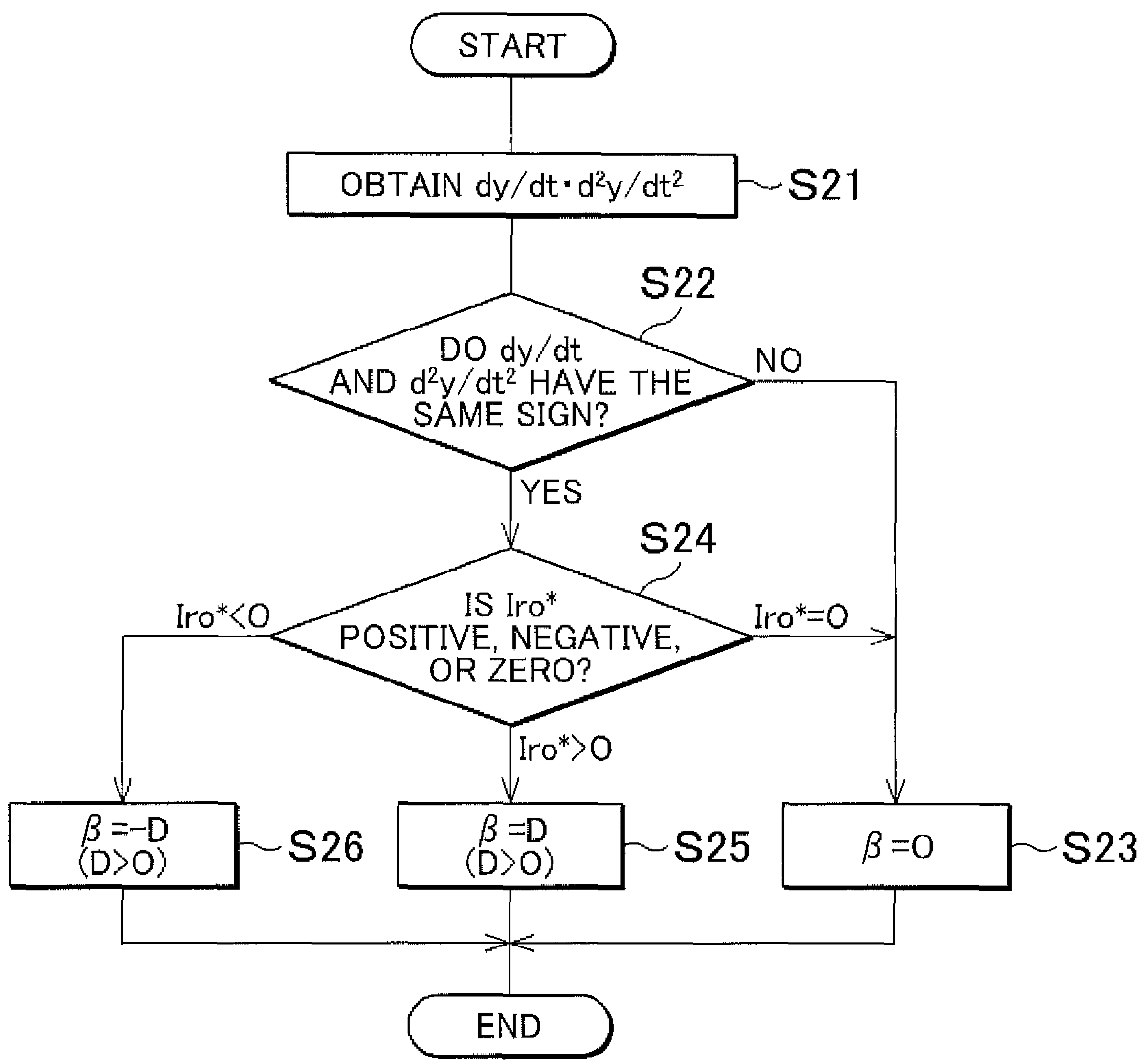

12A
31
VEHICLE SPEED SENSOR
23
TORQUE SENSOR
11
CCD CAMERA
24
V
T
STEERING ASSIST CURRENT VALUE SETTING UNIT
41
Is*
LANE KEEP ASSIST CURRENT VALUE SETTING UNIT
43A
LANE KEEP ASSIST CURRENT VALUE CALCULATION UNIT
51
CORRECTION VALUE SETTING UNIT
52A
INFORMATION OBTAINING UNIT
42
y
dy/dt
d²y/dt²
Iro*
β
53A
Ir*
44
I*
45
PI CONTROL UNIT
46
PWM CONTROL UNIT
47
DRIVE CIRCUIT
32
CURRENT DETECTION CIRCUIT
33
I
M
18

FIG. 14


START
OBTAIN dy/dt·d²y/dt²
S21
S22
DO dy/dt AND d²y/dt² HAVE THE SAME SIGN?
NO
YES
S24
IS Iro* POSITIVE, NEGATIVE, OR ZERO?
Iro*<0
Iro*=0
Iro*>0
β=−D (D>0)
S26
β=D (D>0)
S25
β=0
S23
END

STEERING ASSIST DEVICE

INCORPORATION BY REFERENCE

The disclosure of Japanese Patent Application No. 2015-120563 filed on Jun. 15, 2015 including the specification, drawings and abstract, is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to steering assist devices for vehicles, and more particularly to steering assist devices that prevent a running vehicle from deviating from its lane.

2. Description of the Related Art

If a vehicle deviates from its lane on a highway etc. due to driver's carelessness or a road surface condition, there is a risk that the vehicle may contact other vehicle(s) or a guardrail. As a solution, lane departure warning systems are developed which obtain road surface information and relative position information between the vehicle and its lane based on an image shot by a camera mounted on the vehicle and warn the driver when the vehicle is about to deviate from its lane. See, e.g., Japanese Patent Application Publication No. 2013-212839 (JP 2013-212839 A), Japanese Patent No. 4292562 (JP 4292562 B), and Japanese Patent Application Publication No. H11-34774 (JP H11-34774 A).

SUMMARY OF THE INVENTION

It is one object of the present invention to provide a steering assist device that can quickly return a vehicle to a target travel line when it deviates from the target travel line.

According to one aspect of the present invention, a steering assist device includes: an electric motor that applies a steering driving force to a steering operation mechanism of a vehicle; an information obtaining unit that obtains a lateral deviation of the vehicle from a target travel line, a lateral deviation change rate or a rate of change in the lateral deviation per unit time, and a rate of change in the lateral deviation change rate per unit time; a steering assist current value setting unit that sets a steering assist current value corresponding to a target value of steering assist torque; a lane keep assist current value calculation unit that calculates a lane keep assist current value that makes the lateral deviation and the lateral deviation change rate closer to zero, based on the lateral deviation and the lateral deviation change rate obtained by the information obtaining unit; a correction unit that corrects the lane keep assist current value calculated by the lane keep assist current value calculation unit so that an absolute value of the lane keep assist current value increases, if the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time obtained by the information obtaining unit have the same sign; a target current value calculation unit that calculates a target current value by using the steering assist current value set by the steering assist current value setting unit and the lane keep assist current value corrected by the correction unit; and a control unit that drivingly controls the electric motor based on the target current value calculated by the target current value calculation unit.

The steering assist device of the above aspect can generate lane keep assist torque that makes the lateral deviation and the lateral deviation change rate closer to zero. Since the vehicle is thus guided so as to make the lateral deviation closer to zero, the vehicle can be guided toward the target travel line. Moreover, since the vehicle is guided so as to make the lateral deviation change rate closer to zero, the vehicle can be guided so as to make a lateral centerline of the vehicle parallel to the target travel line when the vehicle is traveling near the target travel line. The vehicle can thus be guided so as to avoid deviating from its lane.

In the steering assist device of the above aspect, the lane keep assist current value calculated by the lane keep assist current value calculation unit is corrected so that the absolute value of the lane keep assist current value increases, if the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time have the same sign. The case where both the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time have the same sign corresponds to the state where the degree to which the vehicle deviates from the target travel line is increasing. The state where the degree to which the vehicle deviates from the target travel line is increasing refers to the state where both the lateral deviation and the lateral deviation change rate are changing in a direction away from zero. Accordingly, in the present invention, the lane keep assist torque can be increased in the state where the degree to which the vehicle deviates from the target travel line is increasing. The vehicle can therefore be rapidly returned toward the target travel line if it deviates from the target travel line.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and further features and advantages of the invention will become apparent from the following description of example embodiments with reference to the accompanying drawings, wherein like numerals are used to represent like elements and wherein:

FIG. **1** is a schematic diagram showing a schematic configuration of an electric power steering system to which a steering assist device according to an embodiment of the present invention is applied;

FIG. **2** is a block diagram showing an electrical configuration of an electronic control unit (ECU);

FIG. **3** is a graph showing an example of setting a steering assist current value Is* with respect to detected steering torque T;

FIG. **4** is a schematic diagram illustrating operation of an information obtaining unit;

FIG. **5** is a block diagram showing an electrical configuration of a lane keep assist current value calculation unit;

FIG. **6**A is a graph showing an example of the relationship of a first lane keep assist current value Ir**1*** to a lateral deviation y;

FIG. **6**B is a graph showing another example of the relationship of the first lane keep assist current value Ir**1*** to the lateral deviation y;

FIG. **6**C is a graph showing still another example of the relationship of the first lane keep assist current value Ir**1*** to the lateral deviation y;

FIG. **7**A is a graph showing an example of the relationship of a second lane keep assist current value Ir**2*** to a lateral deviation change rate dy/dt;

FIG. **7**B is a graph showing another example of the relationship of the second lane keep assist current value Ir**2*** to the lateral deviation change rate dy/dt;

FIG. **8** is a graph showing an example of setting vehicle speed gain Gv with respect to a vehicle speed V;

FIG. **9** is a flowchart illustrating an example of operation of a correction gain setting unit;

FIG. **10** is a flowchart illustrating another example of operation of the correction gain setting unit;

FIG. **11** is a block diagram showing a modification of the lane keep assist current value calculation unit;

FIG. **12** is a graph showing the relationship between the detected steering torque T and control steering torque Ts;

FIG. **13** is a block diagram showing another example of the configuration of the ECU; and

FIG. **14** is a flowchart illustrating an example of operation of a correction value setting unit.

DETAILED DESCRIPTION OF EMBODIMENTS

An embodiment of the present invention will be described in detail below with reference to the accompanying drawings.

FIG. **1** is a schematic diagram showing a schematic configuration of an electric power steering system to which a steering assist device according to an embodiment of the present invention is applied.

An electric power steering system (EPS) **1** includes a steering wheel **2** serving as a steering member that steers a vehicle, a steering operation mechanism **4** that steers steered wheels **3** in accordance with the rotation of the steering wheel **2**, and a steering assist mechanism **5** that assists driver's steering operation. The steering wheel **2** and the steering operation mechanism **4** are mechanically coupled to each other via a steering shaft **6** and an intermediate shaft **7**.

The steering shaft **6** includes an input shaft **8** coupled to the steering wheel **2** and an output shaft **9** coupled to the intermediate shaft **7**. The input shaft **8** and the output shaft **9** are coupled to each other via a torsion bar **10** so as to be rotatable relative to each other.

A torque sensor **11** is disposed around the torsion bar **10**. The torque sensor **11** detects steering torque T applied to the steering wheel **2**, based on the relative rotation displacement between the input shaft **8** and the output shaft **9**. For example, in the present embodiment, the torque sensor **11** detects torque for steering to the right as positive steering torque T and detects torque for steering to the left as negative steering torque T. The larger the absolute value of the detected steering torque T is, the larger the magnitude of the steering torque T is.

The steering operation mechanism **4** is a rack and pinion mechanism including a pinion shaft **13** and a rack shaft **14** serving as a steering operation shaft. The steered wheels **3** are each coupled to corresponding one of the ends of the rack shaft **14** via a tie rod **15** and a knuckle arm (not shown). The pinion shaft **13** is coupled to the intermediate shaft **7**. The pinion shaft **13** rotates in accordance with the steering operation of the steering wheel **2**. A pinion **16** is coupled to the tip end (the lower end in FIG. **1**) of the pinion shaft **13**.

The rack shaft **14** extends linearly in the lateral direction of the vehicle. The rack shaft **14** has a rack **17** in its intermediate portion in the axial direction. The rack **17** meshes with the pinion **16**. The pinion **16** and the rack **17** convert rotation of the pinion shaft **13** to axial movement of the rack shaft **14**. The steered wheels **3** can be steered by moving the rack shaft **14** in the axial direction.

When the steering wheel **2** is rotated by driver's steering operation, this rotation of the steering wheel **2** is transmitted to the pinion shaft **13** via the steering shaft **6** and the intermediate shaft **7**. Rotation of the pinion shaft **13** is converted to axial movement of the rack shaft **14** by the pinion **16** and the rack **17**. The steered wheels **3** are thus steered.

The steering assist mechanism **5** includes a steering assist electric motor **18** and a speed reduction mechanism **19**. The electric motor **18** generates a steering assist force (steering assist torque), and the speed reduction mechanism **19** transmits the output torque of the electric motor **18** to the steering operation mechanism **4**. The speed reduction mechanism **19** is a worm gear mechanism that includes a worm shaft **20** and a worm wheel **21** meshing with the worm shaft **20**. The speed reduction mechanism **19** is accommodated in a gear housing **22** serving as a transmission mechanism housing.

The worm shaft **20** is rotationally driven by the electric motor **18**. The worm wheel **21** is coupled to the steering shaft **6** so as to be rotatable in the same direction as the steering shaft **6**. The worm wheel **21** is rotationally driven by the worm shaft **20**.

When the worm shaft **20** is rotationally driven by the electric motor **18**, the worm wheel **21** is rotationally driven and the steering shaft **6** is rotated accordingly. The rotation of the steering shaft **6** is transmitted to the pinion shaft **13** via the intermediate shaft **7**. Rotation of the pinion shaft **13** is converted to axial movement of the rack shaft **14**, whereby the steered wheels **3** are steered. That is, the steered wheels **3** are steered by rotationally driving the worm shaft **20** by the electric motor **18**. The electric motor **18** is a motor that generates a steering driving force for steering the steered wheels **3**.

The vehicle is provided with a vehicle speed sensor **23** that detects the vehicle speed V. A charge coupled device (CCD) camera **24** is also mounted on the vehicle. The CCD camera **24** shoots the road ahead in the direction in which the vehicle is traveling.

The steering torque T detected by the torque sensor **11**, the vehicle speed V detected by the vehicle speed sensor **23**, and an image signal output from the CCD camera **24** are input to an electronic control unit (ECU) **12**. The ECU **12** controls the electric motor **18** based on these input signals.

FIG. **2** is a block diagram showing an electrical configuration of the ECU **12**.

The ECU **12** includes a microcomputer **31**, a drive circuit (inverter circuit) **32**, and a current detection circuit **33**. The microcomputer **31** controls the electric motor **18**. The drive circuit **32** is controlled by the microcomputer **31** to supply electric power to the electric motor **18**. The current detection circuit **33** detects a motor current (actual current value) I flowing in the electric motor **18**.

The microcomputer **31** includes a central processing unit (CPU) and a memory (a read only memory (ROM), a random access memory (RAM), a nonvolatile memory, etc.). The microcomputer **31** functions as a plurality of functional processing units by executing a predetermined program. The plurality of functional processing units include a steering assist current value setting unit **41**, an information obtaining unit **42**, a lane keep assist current value setting unit **43**, a target current value calculation unit **44**, a current deviation calculation unit **45**, a proportional-integral (PI) control unit **46**, and a pulse width modulation (PWM) control unit **47**.

The steering assist current value setting unit **41** sets a steering assist current value Is* that is a motor current value corresponding to a target value of the steering assist torque. The steering assist current value setting unit **41** sets the steering assist current value Is* based on the steering torque T detected by the torque sensor **11** and the vehicle speed V detected by the vehicle speed sensor **23**. FIG. **3** shows an example of setting the steering assist current value Is* with respect to the detected steering torque T. For example, the detected steering torque T takes a positive value in the case where it is the torque for steering to the right, and takes a negative value in the case where it is the torque for steering to the left. The steering assist current value Is* is set to a positive value when a steering assist force for steering to the right should be generated by the electric motor **18**, and is set to a negative value when a steering assist force for steering to the left should be generated by the electric motor **18**.

The steering assist current value Is* takes a positive value when the detected steering torque T has a positive value, and takes a negative value when the detected steering torque T has a negative value. The steering assist current value Is* is set to zero when the detected steering torque T has a very small value in the range of −T**1** to T**1** (torque dead band) (e.g., T**1**=0.4 N·m). In the case where the detected steering torque T is out of the range of −T**1** to T**1**, the steering assist current value Is* is set so that its absolute value increases as the absolute value of the detected steering torque T increases. The steering assist current value Is* is set so that its absolute value decreases as the vehicle speed V detected by the vehicle speed sensor **23** increases. A large steering assist force can thus be generated when the vehicle is traveling at low speeds, and the steering assist force can be reduced when the vehicle is traveling at high speeds.

As shown in FIG. **4**, the information obtaining unit **42** recognizes a pair of lane marking lines (white lines) Ll, Lr indicating a lane in which a vehicle **100** is traveling, and recognizes the lane in which the vehicle **100** is traveling, based on an image shot by the CCD camera **24**. The information obtaining unit **42** sets a target travel line Ls of the vehicle **100** within the recognized lane. In the present embodiment, the target travel line Ls is set in the middle of the width of the vehicle's lane. The information obtaining unit **42** obtains a lateral deviation y of the vehicle **100** from the target travel line Ls, a lateral deviation change rate dy/dt, or a rate of change in lateral deviation y per unit time, and a change rate d^2y/dt^2, or a rate of change in lateral deviation change rate dy/dt per unit time. Hereinafter, the change rate d^2y/dt^2 (the rate of change in lateral deviation change rate dy/dt per unit time) is sometimes referred to as the "second derivative value d^2y/dt^2 of the lateral deviation y."

The lateral deviation y of the vehicle **100** represents the distance from a reference position C of the vehicle **100** to the target travel line Ls as viewed in plan. The reference position C of the vehicle **100** may be the position of the center of gravity of the vehicle **100** or may be the position where the CCD camera **24** is placed in the vehicle **100**. In the present embodiment, the lateral deviation y is set so that the sign of the lateral deviation y is positive if the reference position C of the vehicle **100** is located on the right side of the target travel line Ls, and is negative if the reference position C of the vehicle **100** is located on the left side of the target travel line Ls, as viewed in the direction in which the vehicle **100** is traveling.

The lateral deviation change rate dy/dt may be the deviation (y(t)−y(t−Δt)) between a lateral deviation y(t) obtained this time and a lateral deviation y(t−Δt) obtained a predetermined unit time Δt ago. The lateral deviation change rate dy/dt may be the deviation (y(t+Δt)−y(t)) between a predicted lateral deviation y(t+Δt) after the predetermined unit time Δt and the lateral deviation y(t) obtained this time. The predicted lateral deviation y(t+Δt) may be obtained in view of the vehicle speed, the yaw angle, etc.

The lateral deviation change rate dy/dt may be the deviation (y(t+Δtx+Δt)−y(t+Δtx)) between a predicted lateral deviation y(t+Δtx) at time t**1** after a predetermined time Δtx and a predicted lateral deviation y(t+Δtx+Δt) at time t**2** that is the predetermined unit time Δt after time t**1**. The predicted lateral deviations y(t+Δtx), y(t+Δtx+Δt) may be obtained in view of the vehicle speed, the yaw angle, etc. Since a method for calculating or predicting the lateral deviation y of a vehicle by shooting the road ahead in the direction in which the vehicle is traveling is known in the art, as described in patent documents such as JP 2013-212839 A, JP 4292562 B, and JP H11-34774 A, description thereof will be omitted.

For example, the second derivative value d^2y/dt^2 of the lateral deviation y may be the deviation ((dy/dt)(t)−(dy/dt)(t−Δt)) between a lateral deviation change rate (dy/dt)(t) obtained this time and a lateral deviation change rate (dy/dt)(t−Δt) obtained a predetermined unit time Δt ago.

Referring back to FIG. **2**, the lane keep assist current value setting unit **43** sets a lane keep assist current value Ir* based on the vehicle speed V, the lateral deviation y, the lateral deviation change rate dy/dt, and the second derivative value d^2y/dt^2 of the lateral deviation y. The lane keep assist current value Ir* is a value that is used to cause the vehicle **100** to travel along the target travel line Ls. The lane keep assist current value setting unit **43** will be described in detail later.

The target current value calculation unit **44** calculates a target current value I* by adding the lane keep assist current value Ir* set by the lane keep assist current value setting unit **43** to the steering assist current value Is* set by the steering assist current value setting unit **41**. The current deviation calculation unit **45** calculates the deviation between the target current value I* obtained by the target current value calculation unit **44** and the actual current value I detected by the current detection circuit **33** (current deviation ΔI=I*−I).

The PI control unit **46** generates a drive command value by performing a PI operation on the current deviation ΔI calculated by the current deviation calculation unit **45**. The drive command value is a value that is used to control the current I flowing in the electric motor **18** toward the target current value I*. The PWM control unit **47** generates a PWM control signal having a duty cycle corresponding to the drive command value and supplies the PWM control signal to the drive circuit **32**. Electric power corresponding to the drive command value is thus supplied to the electric motor **18**.

The current deviation calculation unit **45** and the PI control unit **46** form a current feedback controller. The current feedback controller serves to control the motor current I flowing in the electric motor **18** toward the target current value I*.

The lane keep assist current value setting unit **43** will be described in detail. As shown in FIG. **2**, the lane keep assist current value setting unit **43** includes a lane keep assist current value calculation unit **51**, a correction gain setting unit **52**, and a gain multiplication unit **53**.

The lane keep assist current value calculation unit **51** calculates a lane keep assist current value Iro* based on the lateral deviation y and the lateral deviation change rate dy/dt which are obtained by the information obtaining unit **42**. The lane keep assist current value Iro* corresponds to lane keep assist torque that makes the lateral deviation y and the lateral deviation change rate dy/dt closer to zero.

FIG. **5** is a block diagram showing an electrical configuration of the lane keep assist current value calculation unit **51**. The lane keep assist current value calculation unit **51** includes a first current value calculation unit **61**, a second current value calculation unit **62**, an addition unit **63**, a vehicle speed gain setting unit **64**, and a multiplication unit **65**.

The first current value calculation unit **61** calculates a first lane keep assist current value Ir**1*** based on the lateral deviation y. The second current value calculation unit **62** calculates a second lane keep assist current value Ir**2*** based on the lateral deviation change rate dy/dt. The addition unit **63** calculates a third lane keep assist current value Ir3* (=Ir**1***+Ir**2***) by adding the first lane keep assist current value Ir**1*** calculated by the first current value calculation unit **61** and the second lane keep assist current value Ir**2*** calculated by the second current value calculation unit **62**. The vehicle speed gain setting unit **64** sets vehicle speed gain Gv according to the vehicle speed V. The multiplication unit **65** calculates the lane keep assist current value Iro* (=Gv·(Ir**1***+Ir**2***)) by multiplying the third lane keep assist current value Ir**3***(=In**1***+Ir**2***) calculated by the addition unit **63** by the vehicle speed gain Gv set by the vehicle speed gain setting unit **64**. The lane keep assist current value Iro* is applied to the gain multiplication unit **53**.

The first current value calculation unit **61**, the second current value calculation unit **62**, and the vehicle speed gain setting unit **64** will be more specifically described.

The first current value calculation unit **61** calculates the first lane keep assist current value Ir**1*** based on a map or an arithmetic expression that represents the relationship of the first lane keep assist current value Ir**1*** to the preset lateral deviation y. The second current value calculation unit **62** calculates the second lane keep assist current value Ir**2*** based on a map or an arithmetic expression that represents the relationship of the second lane keep assist current value Ir**2*** to the preset lateral deviation change rate dy/dt.

It is preferable that the first current value calculation unit **61** and the second current value calculation unit **62** calculate the first lane keep assist current value Ir**1*** and the second lane keep assist current value Ir**2*** as follows, where a**1** and a**2** represent constants of the same sign, b**1** represents a degree of a natural number of two or larger, and b**2** represents a degree of a natural number smaller than b**1**.

In the case where b**1** is set to an odd number, it is preferable that the first current value calculation unit **61** calculate the first lane keep assist current value Ir**1*** based on the relationship between y and Ir**1*** as given by the function $Ir1^* = a1 \cdot y^{b1}$. In the case where b**1** is set to an even number, it is preferable that the first current value calculation unit **61** calculate the first lane keep assist current value Ir**1*** based on the relationship between y and Ir**1*** as given by the function $Ir1^* = a1 \cdot y^{b1}$ for $y \geq 0$ and given by the function $Ir1^* = -a1 \cdot y^{b1}$ for $y < 0$.

In the case where b**2** is set to an odd number, it is preferable that the second current value calculation unit **62** calculate the second lane keep assist current value Ir**2*** based on the relationship between dy/dt and Ir**2*** as given by the function $Ir2^* = a2 \cdot (dy/dt)^{b2}$. In the case where b**2** is set to an even number, it is preferable that the second current value calculation unit **62** calculate the second lane keep assist current value Ir**2*** based on the relationship between dy/dt and Ir**2*** as given by the function $Ir2^*\ a2 \cdot (dy/dt)^{b2}$ for $dy/dt \geq 0$ and given by the function $Ir2^* = -a2 \cdot (dy/dt)^{b2}$ for $dy/dt < 0$.

As described above, in the present embodiment, the steering assist current value Is* is set to a positive value when a steering assist force for steering to the right should be generated by the electric motor **18**, and is set to a negative value when a steering assist force for steering to the left should be generated by the electric motor **18**. The lateral deviation y is set so that the sign of the lateral deviation y is positive if the reference position of the vehicle is located on the right side of the target travel line Ls, and is negative if the reference position of the vehicle is located on the left side of the target travel line Ls, as viewed in the direction in which the vehicle is traveling. In the case where the sign of the lateral deviation y is set in this manner, the constants a**1**, a**2** are set to negative values.

In the case where both the sign of the steering assist current value Is* and the sign of the lateral deviation y are set in the opposite manner to the present embodiment, the constants a**1**, a**2** are also set to negative values.

On the other hand, in the case where the sign of the steering assist current value Is* is set in a manner similar to the present embodiment and the sign of the lateral deviation y is set in the opposite manner to the present embodiment, or in the case where the sign of the steering assist current value Is* is set in the opposite manner to the present embodiment and the sign of the lateral deviation y is set in a manner similar to the present embodiment, the constants a**1**, a**2** are set to positive values.

The reason why it is preferable that the first current value calculation unit **61** and the second current value calculation unit **62** calculate the first lane keep assist current value Ir**1*** and the second lane keep assist current value Ir**2*** in the manner described above will be described.

In general, in the case where a is a constant in the function given by $f(x) = ax^b$ (b represents a degree of a natural number), the absolute value of f(x) increases as the absolute value of x increases. In the case where the value of b is two or larger, the average rate of change increases as the absolute value of x increases. The average rate of change is the amount of change in f(x) divided by the amount of change in x.

In the case where the value of b**1** is two or larger, the absolute value of the first lane keep assist current value Ir**1*** increases as the absolute value of the lateral deviation y increases, and the average rate of change (rate of increase in absolute value of the first lane keep assist current value Ir**1***) increases as the absolute value of the lateral deviation y increases. The vehicle can therefore be more rapidly guided toward the target travel line (in the present embodiment, toward the middle of the width of the vehicle's lane).

In the function given by $f(x) = ax^b$, the average rate of change in the range where the absolute value of x is smaller than one decreases as the value of b increases. The average rate of change in the range where the absolute value of x is equal to or larger than one increases as the value of b increases.

When a**1** is equal to a**2** and b**1** is larger than b**2**, the average rate of change in first lane keep assist current value Ir**1*** in the range where the absolute value of the lateral deviation y is smaller than one is lower than that in second lane keep assist current value Ir**2*** in the range where the absolute value of the lateral deviation change rate dy/dt is smaller than one. The average rate of change in first lane keep assist current value Ir**1*** in the range where the absolute value of the lateral deviation y is larger than one is higher than that in second lane keep assist current value Ir**2*** in the range where the absolute value of the lateral deviation change rate dy/dt is larger than one.

Accordingly, when the reference position of the vehicle is located in an area away from the target travel line, the function to make the lateral deviation y closer to zero by the first lane keep assist current value Ir**1*** tends to be stronger than that to make the lateral deviation change rate dy/dt closer to zero by the second lane keep assist current value Ir**2***, even if the sign of the second lane keep assist current value Ir**2*** is opposite to that of the first lane keep assist current value Ir**1***. The vehicle can therefore be guided toward the target travel line (in the present embodiment, toward the middle of the width of the vehicle's lane) even if the sign of the second lane keep assist current value Ir2* is opposite to that of the first lane keep assist current value Ir1*.

The second lane keep assist current value Ir2* according to the magnitude of the lateral deviation change rate dy/dt is obtained regardless of the value of the lateral deviation y. The vehicle can therefore be guided so as to make the lateral centerline of the vehicle parallel to the target travel line, even if the reference position of the vehicle is located in an area close to the target travel line.

In the present embodiment, the first current value calculation unit **61** calculates the first lane keep assist current value Ir**1*** based on a map storing the relationship of the first lane keep assist current value Ir**1*** to the lateral deviation y, as shown in FIG. **6**A, or an arithmetic expression representing this relationship. In the example of FIG. **6**A, the first lane keep assist current value Ir**1*** is represented by the cubic function $Ir1^*=a1\cdot y^3$, where a**1** is a negative constant. That is, this function corresponds to the case where a**1** is negative and b**1** is three.

For example, the first current value calculation unit **61** may calculate the first lane keep assist current value Ir**1*** based on a map storing the relationship of the first lane keep assist current value Ir**1*** to the lateral deviation y, as shown in FIG. **6**B, or an arithmetic expression representing this relationship. The curve shown in FIG. **6**B is created by translating the curve in the region where Ir**1*** is zero or larger in FIG. **6**A in the direction of the abscissa by −A (A>0) and translating the curve in the region where Ir**1*** is smaller than zero in FIG. **6**A in the direction of the abscissa by +A. In the curve of FIG. **6**B, a dead band where the first lane keep assist current value Ir**1*** is zero is set in the range where the lateral deviation y is −A (A>0) to A.

For example, the first current value calculation unit **61** may calculate the first lane keep assist current value Ir**1*** based on a map storing the relationship of the first lane keep assist current value Ir**1*** to the lateral deviation y, as shown in FIG. **6**C, or an arithmetic expression representing this relationship. In the example of FIG. **6**C, the first lane keep assist current value Ir**1*** is given by the quadratic function $Ir1^*=a1\cdot y^2$ for y≥0 and is given by the quadratic function $Ir1^*=-a1\cdot y^2$ for y<0, where a**1** is a negative constant. This function corresponds to the case where a**1** is negative and b**1** is two.

In the present embodiment, the second current value calculation unit **62** calculates the second lane keep assist current value Ir**2*** based on a map storing the relationship of the second lane keep assist current value Ir**2*** to the lateral deviation change rate dy/dt, as shown in FIG. **7**A, or an arithmetic expression representing this relationship. In the example of FIG. **7**A, the second lane keep assist current value Ir**2*** is represented by the linear function $Ir2^*=a2\cdot dy/dt$, where a**2** is a negative constant. That is, this function corresponds to the case where a**2** is negative and b**2** is one. A dead band where the second lane keep assist current value Ir**2*** is zero may be set in the range where the absolute value of the lateral deviation change rate dy/dt is close to zero.

For example, the second current value calculation unit **62** may calculate the second lane keep assist current value Ir**2*** based on a map storing the relationship of the second lane keep assist current value Ir**2*** to the lateral deviation change rate dy/dt, as shown in FIG. **7**B, or an arithmetic expression representing this relationship. In the example of FIG. **7**B, the second lane keep assist current value Ir**2*** is given by the quadratic function $Ir2^*=a2\cdot(dy/dt)^2$ for dy/dt≥0 and is given by the quadratic function $Ir2^*=-a2\cdot(dy/dt)^2$ for dy/dt<0, where a**2** is a negative constant. This function corresponds to the case where a**2** is negative and b**2** is two.

Referring back to FIG. **5**, the vehicle speed gain setting unit **64** sets the vehicle speed gain Gv based on the vehicle speed V detected by the vehicle speed sensor **23**. FIG. **8** shows an example of setting the vehicle speed gain Gv with respect to the vehicle speed V. In the example of FIG. **8**, the vehicle speed gain Gv is fixed to zero in the range where the vehicle speed V is close to zero, and is fixed to one in the range where the vehicle speed V is higher than a predetermined value. When the vehicle speed V is in the intermediate range, the vehicle speed gain G is set according to the characteristics in which the vehicle speed gain Gv increases from zero to one with the vehicle speed V.

The lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** is applied to the gain multiplication unit **53** (see FIG. **2**).

Referring back to FIG. **2**, the correction gain setting unit **52** sets correction gain G based on the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y which are obtained by the information obtaining unit **42**. The correction gain G is used to correct the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51**. Operation of the correction gain setting unit **52** will be described in detail later.

The gain multiplication unit **53** corrects the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** by multiplying the lane keep assist current value Iro* by the correction gain G set by the correction gain setting unit **52**. The corrected lane keep assist current value G·Iro* is applied as the final lane keep assist current value Ir* to the target current value calculation unit **44**. The correction gain setting unit **52** and the gain multiplication unit **53** form a correction unit that corrects the lane keep assist current value Iro*.

FIG. **9** is a flowchart illustrating an example of operation of the correction gain setting unit **52**. The process of FIG. **9** is repeatedly performed in predetermined calculation cycles.

The correction gain setting unit **52** obtains the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y (step S**1**). The correction gain setting unit **52** determines if the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y (step S**2**). For example, the correction gain setting unit **52** may determine that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is positive, and may determine that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is zero or negative.

If the correction gain setting unit **52** determines that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y (step S**2**: NO), it sets the correction gain G to one (step S**3**). In this case, the gain multiplication unit **53** outputs the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** as it is. The correction gain setting unit **52** thus ends the process of the current calculation cycle.

If the correction gain setting unit **52** determines in step S**2** that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y (step **S2**: YES), it sets the correction gain G to a predetermined value α that is larger than one (step **S4**). In this case, the gain multiplication unit **53** outputs the lane keep assist current value Ir* whose absolute value is larger than that of the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** and whose sign is the same as that of the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51**. The correction gain setting unit **52** thus ends the process of the current calculation cycle.

The reason why the correction gain setting unit **52** sets the correction gain G to the predetermined value α that is larger than one if it determines that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y will be described.

The state where both the lateral deviation y and the lateral deviation change rate dy/dt are changing in a direction away from zero corresponds to the state where the degree to which the vehicle deviates from the target travel line is increasing. In the state where both the lateral deviation y and the lateral deviation change rate dy/dt are changing in the direction away from zero, the sign of the lateral deviation change rate dy/dt or a first derivative value of the lateral deviation y is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y. Accordingly, if the sign of the lateral deviation change rate dy/dt or the first derivative value of the lateral deviation y is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y, it can be determined that the degree to which the vehicle deviates from the target travel line is increasing.

The correction gain setting unit **52** thus sets the correction gain G to the predetermined value α that is larger than one if the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y. Accordingly, in the state where the degree to which the vehicle deviates from the target travel line is increasing, the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** can be corrected so that its absolute value increases. The lane keep assist torque can thus be increased in the state where the degree to which the vehicle deviates from the target travel line is increasing. The vehicle can therefore be rapidly returned toward the target travel line if it deviates from the target travel line.

FIG. **10** is a flowchart illustrating another example of operation of the correction gain setting unit **52**. The process of FIG. **10** is repeatedly performed in predetermined calculation cycles.

The correction gain setting unit **52** obtains the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y (step **S11**). The correction gain setting unit **52** calculates first correction gain G**1** based on the following formula (1) (step **S12**).

$$G1=|(dy/dt)\cdot K1\times(d^2y/dt^2)\cdot K2| \quad (1)$$

where K**1** and K**2** represent preset positive coefficients.

The correction gain setting unit **52** then determines if the first correction gain G**1** is larger than one (step **S13**).

If the first correction gain G**1** is one or less (step **S13**: NO), the correction gain setting unit **52** sets the first correction gain G**1** to a predetermined value γ larger than one (step **S14**) and proceeds to step **S15**. If the correction gain setting unit **52** determines in step **S13** that the first correction gain G**1** is larger than one (step **S13**: YES), it proceeds to step **S15**.

In step **S15**, the correction gain setting unit **52** determines if the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y. For example, the correction gain setting unit **52** may determine that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is positive, and may determine that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is zero or negative.

If the correction gain setting unit **52** determines that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y (step **S15**: NO), it sets the final correction gain G to one (step **S16**). The correction gain setting unit **52** thus ends the process of the current calculation cycle.

If the correction gain setting unit **52** determines in step **S15** that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y (step **S15**: YES), it sets the final correction gain G to the value of the first correction gain G**1** (step **S17**). The correction gain setting unit **52** thus ends the process of the current calculation cycle.

In this modification, the correction gain G that is set if it is determined that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y is set according to the magnitudes of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y. Since the correction gain G can thus be set according to the degree to which the vehicle deviates from the target travel line, the lane keep assist current value can be more appropriately corrected.

FIG. **11** is a block diagram showing a modification of the lane keep assist current value calculation unit **51**.

The lane keep assist current value calculation unit **51** includes a first current value calculation unit **61**, a second current value calculation unit **62**, an addition unit **63**, a vehicle speed gain setting unit **64**, a multiplication unit **65**, a control steering torque setting unit **66**, and a switch unit **67**.

The first current value calculation unit **61** calculates a first lane keep assist current value Ir**1*** by an operation similar to that of the first current value calculation unit **61** in FIG. **5**. The second current value calculation unit **62** calculates a second lane keep assist current value Ir**2*** by an operation similar to that of the second current value calculation unit **62** in FIG. **5**. The addition unit **63** calculates a third lane keep assist current value Ir**3***Ir**1***+Ir**2***) by adding the first lane keep assist current value Ir**1*** and the second lane keep assist current value Ir**2***.

The vehicle speed gain setting unit **64** sets vehicle speed gain Gv according to the vehicle speed V by an operation similar to that of the vehicle speed gain setting unit **64** in FIG. **5**. The multiplication unit **65** calculates a fourth lane keep assist current value Ir**4***(=Gv·(Ir**1***+Ir**2***)) by multiplying the third lane keep assist current value Ir**3*** (Ir**1***+Ir**2***) by the vehicle speed gain Gv.

The control steering torque setting unit **66** sets control steering torque Ts based on the detected steering torque T detected by the torque sensor **11**. FIG. **12** shows an example of setting the control steering torque Ts with respect to the detected steering torque T. A dead band where the control steering torque Ts is zero is set in the region where the absolute value of the detected steering torque T is equal to or smaller than a predetermined value T2 (e.g., T2=0.4 N·m). The control steering torque Ts is set to have the same value as the detected steering torque T in the region where the detected steering torque T is larger than T2 and in the region where the detected steering torque T is smaller than −T2.

The fourth lane keep assist current value Ir4* calculated by the multiplication unit **65** is input to a first input terminal of the switch unit **67**. Zero is input to a second input terminal of the switch unit **67**. The control steering torque Ts calculated by the control steering torque setting unit **66** and the fourth lane keep assist current value Ir4* calculated by the multiplication unit **65** are applied to the switch unit **67** as switch control signals. The switch unit **67** selects one of the fourth lane keep assist current value Ir4* received at the first input terminal and zero received at the second input terminal based on the sign of the control steering torque Ts and the sign of the fourth lane keep assist current value Ir4*, and outputs the selected one of the fourth lane keep assist current value Ir4* and zero as a lane keep assist current value Iro*.

The sign of the control steering torque Ts represents the steering direction in which the driver steers the vehicle. The sign of the fourth lane keep assist current value Ir4* represents the steered direction in which the steered wheels are steered, which corresponds to the fourth lane keep assist current value Ir4* (lane keep assist torque). If the steering direction represented by the sign of the control steering torque Ts is different from the steered direction represented by the sign of the fourth lane keep assist current value Ir4*, the switch unit **67** selects the fourth lane keep assist current value Ir4* received at the first input terminal, and outputs the fourth lane keep assist current value Ir4* as the lane keep assist current value Iro*.

If the steering direction represented by the sign of the control steering torque Ts is the same as the steered direction represented by the sign of the fourth lane keep assist current value Ir4*, the switch unit **67** selects zero received at the second input terminal, and outputs zero as the lane keep assist current value Iro*. This is because it is considered that the driver is steering the vehicle toward the target travel line when the steering direction represented by the sign of the control steering torque Ts is the same as the steered direction represented by the sign of the fourth lane keep assist current value Ir4*. As described above, the dead band where the control steering torque Ts is zero is set in the region where the absolute value of the detected steering torque T is equal to or smaller than the predetermined value T2. This can restrain frequent inversions of the sign of the control steering torque Ts in the region where the detected steering torque T is small. This can restrain frequent switching between the fourth lane keep assist current value Ir4* and zero and can therefore restrain frequent fluctuations in motor torque generated by the electric motor **18**.

In this modification, if the sign of the control steering torque Ts is different from that of the fourth lane keep assist current value Ir4*, the switch unit **67** selects the fourth lane keep assist current value Ir4* and outputs the fourth lane keep assist current value Ir4* as the lane keep assist current value Iro*. For example, the switch unit **67** may determine that the sign of the control steering torque Ts is different from that of the fourth lane keep assist current value Ir4* when the product of the control steering torque Ts and the fourth lane keep assist current value Ir4* is equal to or smaller than zero (zero or a negative value).

If the sign of the control steering torque Ts is the same as that of the fourth lane keep assist current value Ir4*, the switch unit **67** selects zero and outputs zero as the lane keep assist current value Iro*. For example, the switch unit **67** may determine that the sign of the control steering torque Ts is the same as that of the fourth lane keep assist current value Ir4* when the product of the control steering torque Ts and the fourth lane keep assist current value Ir4* is larger than zero (a positive value).

When the steering direction represented by the sign of the control steering torque Ts is the same as the steered direction represented by the sign of the fourth lane keep assist current value Ir4*, it is considered that the driver is steering the vehicle toward the target travel line. If the lane keep assist torque is generated even though the driver is steering the vehicle toward the target travel line, a steering response (steering reaction force) may be significantly reduced, whereby a steering feel may be degraded or the vehicle may return too much toward the target travel line. In this modification, the lane keep assist current value Iro* is zero when the steering direction represented by the sign of the control steering torque Ts is the same as the steered direction represented by the sign of the fourth lane keep assist current value Ir4*. This can appropriately give the driver a steering response when he/she is steering the vehicle toward the target travel line. This can improve a steering feel and can also restrain the vehicle from returning too much toward the target travel line.

FIG. **13** is a block diagram showing another example of the configuration of the ECU. In FIG. **13**, the portions corresponding to the portions shown in FIG. **2** are denoted by the same reference characters.

An ECU **12**A in FIG. **13** is different from the ECU **12** in FIG. **2** in the configuration of a lane keep assist current value setting unit **43**A. The lane keep assist current value setting unit **43**A includes a lane keep assist current value calculation unit **51**, a correction value setting unit **52**A, and a correction value addition unit **53**A. The lane keep assist current value calculation unit **51** has the same composition as that of the lane keep assist current value calculation unit **51** in FIG. **2**. The lane keep assist current value calculation unit **51** may have the same configuration as that in the modification shown in FIG. **11**.

The correction value setting unit **52**A calculates a correction value β based on the lateral deviation change rate dy/dt, the second derivative value d^2y/dt^2 of the lateral deviation y, and the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51**. Operation of the correction value setting unit **52**A will be described in detail later. The correction value addition unit **53**A corrects the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** by adding the correction value β set by the correction value setting unit **52**A to the lane keep assist current value Iro*. The corrected lane keep assist current value (Iro*β) is applied as a final lane keep assist current value Ir* to the target current value calculation unit **44**.

FIG. **14** is a flowchart illustrating an example of operation of the correction value setting unit **52**A. The process of FIG. **14** is repeatedly performed in predetermined calculation cycles.

The correction value setting unit **52**A obtains the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y (step S**21**). The correction value setting unit **52**A determines if the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y (step S**22**).

For example, the correction value setting unit **52**A may determine that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is positive, and may determine that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y when the product of the lateral deviation change rate dy/dt and the second derivative value d^2y/dt^2 of the lateral deviation y is zero or negative.

If the correction value setting unit **52**A determines that the sign of the lateral deviation change rate dy/dt is different from that of the second derivative value d^2y/dt^2 of the lateral deviation y (step S**22**: NO), it sets the correction value β to zero (step S**23**). In this case, the correction value addition unit **53**A outputs the lane keep assist current value Ira* calculated by the lane keep assist current value calculation unit **51** as it is. The correction value setting unit **52**A thus ends the process of the current calculation cycle.

If the correction value setting unit **52**A determines in step S**22** that the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y (step S**22**: YES), it proceeds to step S**24**. In step S**24**, the correction value setting unit **52**A determines if the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** is a positive value, a negative value, or zero.

If the correction value setting unit **52**A determines that the lane keep assist current value Iro* is a positive value (Iro*>0), it sets the correction value β to a predetermined positive value D (D>0) (step S**25**). In this case, the correction value addition unit **53**A outputs the sum of the lane keep assist current value Iro* (Iro*>0) calculated by the lane keep assist current value calculation unit **51** and the correction value β (=D). The correction value setting unit **52**A thus ends the process of the current calculation cycle.

If the correction value setting unit **52**A determines in step S**24** that the lane keep assist current value Iro* is a negative value (Iro*<0), it sets the correction value β to a predetermined negative value −D (step S**26**). In this case, the correction value addition unit **53**A outputs the sum of the lane keep assist current value Iro* (Iro*<0) calculated by the lane keep assist current value calculation unit **51** and the correction value β (=−D). The correction value setting unit **52**A thus ends the process of the current calculation cycle.

If the correction value setting unit **52**A determines in step S**24** that the lane keep assist current value Iro* is zero (Iro*=0), it sets the correction value β to zero (step S**23**). In this case, the correction value addition unit **53**A outputs the lane keep assist current value Iro* (Iro*=0) calculated by the lane keep assist current value calculation unit **51** as it is. The correction value setting unit **52**A thus ends the process of the current calculation cycle.

In this modification as well, if the sign of the lateral deviation change rate dy/dt is the same as that of the second derivative value d^2y/dt^2 of the lateral deviation y, the lane keep assist current value Iro* calculated by the lane keep assist current value calculation unit **51** can be corrected so that its absolute value increases. The vehicle can therefore be rapidly returned toward the target travel line if it deviates from the target travel line.

Although the embodiment of the present invention is described above, the present invention may be carried out in other forms. For example, a limiter that limits the absolute value of the third lane keep assist current value Ir**3*** (=Ir**1***+Ir**2***) to a predetermined range may be provided between the addition unit **63** (see FIGS. **5** and **11**) and the multiplication unit **65**.

Although the above embodiment includes the multiplication unit **65** (see FIGS. **5** and **11**), the multiplication unit **65** may be omitted. The vehicle speed gain setting unit **64** is not required in the case where the multiplication unit **65** is omitted.

In the above embodiment, the steering assist current value setting unit **41** sets the steering assist current value Is* by using the steering torque T (specifically, based on the steering torque T and the vehicle speed V). However, the steering assist current value setting unit **41** may set the steering assist current value Is* by using a steering angle.

Although the modification of the lane keep assist current value calculation unit **51** (see FIG. **11**) includes the control steering torque setting unit **66**, the control steering torque setting unit **66** may be omitted. In the case where the control steering torque setting unit **66** is omitted, the detected steering torque T detected by the torque sensor **11** is applied to the switch unit **67** instead of the control steering torque Ts. In this case, when the steering direction represented by the sign of the detected steering torque T is different from the steered direction represented by the sign of the fourth lane keep assist current value Ir**4***, the switch unit **67** selects the fourth lane keep assist current value Ir**4*** received at the first input terminal and outputs the fourth lane keep assist current value Ir**4*** as the lane keep assist current value Iro*. When the steering direction represented by the sign of the detected steering torque T is the same as the steered direction represented by the sign of the fourth lane keep assist current value Ir**4***, the switch unit **67** selects zero received at the second input terminal and outputs zero as the lane keep assist current value Iro*.

Although the above embodiment is described with respect to an example in which the present invention is applied to an electric power steering system, the present invention is also applicable to other vehicle steering systems such as a steer-by-wire system.

The present invention is also applicable in an autonomous driving mode in which the steering wheel **2** is not steered by the driver.

What is claimed is:

1. A steering assist device, comprising:

an electric motor that applies a steering driving force to a steering operation mechanism of a vehicle; and

a processor programmed to:

obtain a lateral deviation of the vehicle from a target travel line, a lateral deviation change rate or a rate of change in the lateral deviation per unit time, and a rate of change in the lateral deviation change rate per unit time,

set a steering assist current value corresponding to a target value of steering assist torque,

calculate a lane keep assist current value that makes the lateral deviation and the lateral deviation change rate closer to zero, based on the lateral deviation and the lateral deviation change rate obtained,

correct the calculated lane keep assist current value so that an absolute value of the lane keep assist current value increases, if the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time obtained are both either a positive value or a negative value,

calculate a target current value by using the set steering assist current value and the corrected lane keep assist current value, and drivingly control the electric motor based on the calculated target current value.

2. The steering assist device according to claim **1**, wherein the calculated lane keep assist current value is corrected by multiplying the lane keep assist current value by a correction gain that is larger than one, if the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time obtained are both either a positive value or a negative value.

3. The steering assist device according to claim **2**, wherein the correction gain is calculated based on the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time obtained.

4. The steering assist device according to claim **1**, wherein the calculated lane keep assist current value is corrected by adding a correction value having a same positive or negative sign as that of the lane keep assist current value to the lane keep assist current value, if the lateral deviation change rate and the rate of change in the lateral deviation change rate per unit time obtained are both either a positive value or a negative value.

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